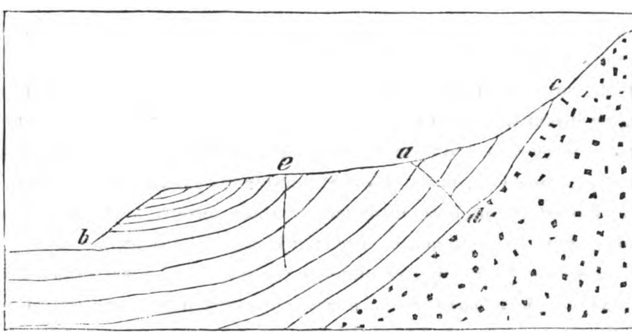

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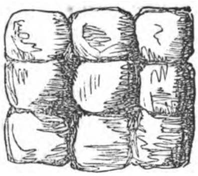
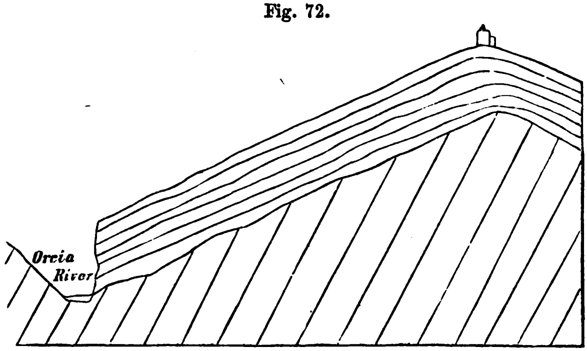


In volcanic countries, and in coal districts, carbonic acid is abundant, both in spring-water and in the gaseous form. Water charged with this gas becomes capable of dissolving limestone. Where the water is exposed to the air, the gas gradually escapes, and the calcareous matter is deposited. Many accumulations of this kind are now taking place. Some have already extended several miles in length, and they are often of great thickness,—in one instance, in Italy, two hundred feet (Fig. 72). It is also

Fig. 72.




probable that many calcareous springs issue below the surface of lakes and seas, and thus, both fresh-water and marine deposits would now be forming. These formations are distinctly stratified, and are white and crystalline, and become solid at the time of deposition.

These dissolved materials are less observed than others, because they do not render the water turbid; but there is reason to believe that several of the aqueous formations, particularly the limestones, have been built up chiefly from them.

2. The *abrading action of rivers* furnishes considerable detrital matter. The general form of the river courses is determined by other causes than the agency of the river itself, yet a river which has a rapid current is continually deepening its channel. We have

proof of this by observing, when the water is low, that irregularity of surface which running water always produces, by wearing away the softer parts of the rock, and leaving the harder in relief. Hence, a river will have its rapids either where the hardest strata occur, and which therefore wear down least rapidly, or where the rock has been hardened by the intrusion or near proximity of dikes.

The abrading power of rivers occasionally becomes greatly increased by water-falls. The force which the water acquires in its descent is such as to excavate a deep cavity at the foot of the fall, reaching back under the ledge from which the water descends. The ledge is therefore constantly being undermined. The cataract of Niagara is peculiar, in having the rock at its base of a soft and friable texture, so that it is rapidly worn away, while the upper rock is a compact siliceous limestone. If the order of superposition had been the reverse, the falls would have been converted into a series of rapids. It is now preserved as a single fall, and as such it has probably cut the gorge, about two hundred feet deep and seven miles in length, through which its waters now reach Lake Ontario. A few years since, a large mass, perhaps half an acre in area, fell from the centre of the horse-shoe fall. Another mass of equal size has recently fallen from the western extremity of the ledge. Thus the fall is gradually receding.

But the foreign substances, such as drift-wood, ice, sand and gravel, with which the waters of a river are occasionally charged, contribute more than everything else to its abrading power. At such times its volume is generally greatest, and its current the most rapid. Its bed is then sometimes perceptibly deepened and widened in a few hours.

Much the greater part, however, of the earthy matter which rivers convey in such quantity to the ocean, is furnished by other means than the eroding action of the river itself. It is the loose material, the soil and alluvium, to which the solid rocks have been reduced by the imperceptible but incessantly operating atmospheric agencies, from which most of the sediment of rivers is

obtained. After a rain, every tributary rivulet is turbid with suspended earthy matter, and it is from these sources that the larger streams receive the most of their sediment.

Some observations have been made for the purpose of ascertaining the quantity of sediment which rivers annually carry into the sea. The Kennebec furnishes materials which, if spread evenly on an area of one mile square, and consolidated into rock of the specific gravity of granite, would have a thickness of six inches. The Merrimac furnishes about two-thirds as much, the Ganges about two hundred and fifty times as much, and the Mississippi two thousand times as much.

Thus, the tendency is, to reduce the highest parts of the land, and to fill up the depressions of the sea; and though we have not data enough to form any reliable estimate of the total annual discharge of sediment into the ocean by rivers, yet they are sufficient to show that the effects of this kind are on a large scale, and to relieve us from any impression that existing agencies are inadequate to the production of the stratified rocks.

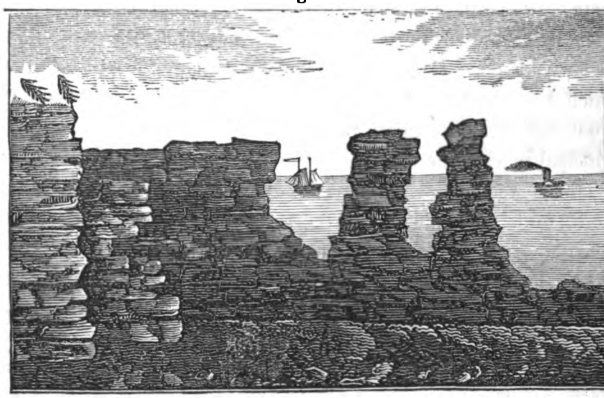
3. *The action of waves* is another means by which detrital matter is furnished. Wherever the shore consists of loose materials, and is favorably situated to be acted upon by the waves, there is annually a sensible encroachment of the sea. Such encroachments are rapidly making in many places; and thus a large amount of sediment is delivered to the waters of the ocean.

The waves also encroach upon the coast when it consists of rocks, even of the most indestructible kinds. They continually beat upon it, undermine the cliffs, and precipitate them into the sea. The tides increase the power of the waves, by varying the place of their action, so as to present the same surface of rock alternately to the action of water and of the air, frost and sun. During storms, the waves have sufficient force to break off fragments of rock from the escarpment, sometimes in masses weighing twenty tons or more, and remove them many rods inland.

A bold, rocky coast always exhibits evidence of a great amount of erosion. The steep escarpments and the high rugged shafts of

rock (Fig. 73) against which the waves now beat are the remnants of masses of rock which once extended further into the sea, but have been worn away by the waves. It is by such agency that the deep inlets and harbors of the coast of New England and Nova Scotia have been excavated.

Fig. 73.



This more violent action of the waves is only occasional; but when of less power, they are incessantly rolling the loosened fragments of rock upon each other, and thus wearing them down to particles small enough to be carried away by the water.

4. The action of waves is confined to the coast, and never extends to great depths. But *marine currents* act principally on the bed of the sea. The temperature of the mass of the ocean is much higher in the equatorial than in the polar regions. At the surface, the difference amounts to sixty degrees. The waters of the torrid zone are thus expanded, and flow over the colder waters of the north and south; while these colder waters of the polar seas flow back, in an under current, towards the equator.

For the same reason,— a difference of temperature,— there will be, in the higher regions of the atmosphere, a current of warm and

moist air flowing from the equator north and south, while the cold and dry air comes in from the polar regions towards the equator. In this way the equatorial waters are carried, in a state of vapor, towards the poles, where they are condensed, and go to increase the currents of water moving towards the equator.

Such are the general causes of the oceanic movements in a north and south direction; but these currents at once become deflected westward, by the diurnal revolution of the earth, as the trade winds do. Hence there results a Pacific equatorial current, which has a motion of about thirty miles a day, and an Atlantic equatorial current, moving from sixty to seventy miles a day. The principal marine currents are shown in Fig. 74.

The currents moving towards the poles are superficial, and therefore do not produce any marked geological effects. But the polar currents, and those which are produced from them, are of great depth, and there is no reason to suppose that they do not move, from their commencement, along the bed of the ocean. There is also reason to suppose that they exist at great depths, where the opposing superficial currents entirely conceal them.

Wherever these currents come to the surface, their motion is undoubtedly greater than it is at the bottom, where it is retarded by the friction which the moving waters encounter, and by the irregularities of the bed of the ocean. It should, however, be remembered, that they move with the weight of the whole superior body of water; and therefore, though the motion be very slow, it will still possess great power.

Any irregularities in the bed of the ocean beneath such a current must be subject to very rapid abrasion. We shall see hereafter, that earthquake vibrations often shiver the rocks at the solid surface; and if any of these ridges at the bottom of the ocean were thus acted upon, the loosened portions would be swept away by the current and deposited at lower levels, or where the current subsides. If, in any instance during an earthquake convulsion, a fault should be produced across one of these marine currents, like the great fault of over five hundred feet in England,

Fig. 74.

the abutment thus thrown up would soon be worn down; and if it consisted of unconsolidated matter, it would be swept away almost bodily.

The effect of such currents will be greatest where they are deflected by a continent or island. Thus, a marine current sets from near New Holland in a direct line to the north of the island of Madagascar, where it is arrested by the African coast, and deflected into the narrow Mozambique channel, and there acquires a velocity of four or five miles an hour. It is impossible that any kind of rock should receive the constant force of such a body of water without being rapidly worn away; and, if there should be any difference of texture in this rocky barrier, the softer portions would yield the most rapidly, and thus valleys might be formed.

It is not improbable that the deep indentation on the western coast of Africa may have been due, in a great measure, to the coast current from the Cape of Good Hope; and that the Caribbean Sea and the Gulf of Mexico may have been excavated by the force of the Atlantic equatorial current being thrown into this angle.

We may regard these currents as oceanic rivers; and it is obvious that the volume of the terrestrial rivers would bear no comparison with that of these currents, and their effects would be equally small in the comparison. The Gulf Stream, and the Mozambique and other similar currents, must be wearing down the valleys through which they flow, to such an extent as to furnish an immense amount of detrital matter for the formation of new rocks.

It is principally to the agency of these deep marine currents that we are to refer those extensive denudations, so abundant on the present continents, such as the wearing out of the intermediate masses of rock between the hills already referred to (Fig. 66), the denudation of the Connecticut river sandstone, and, perhaps, the excavations which have formed Lake Erie and Lake Ontario.

II. *The Transportation of Sediment.*

The detrital matter obtained in these several ways is swept

away by running water. The specific gravity of rocks does not, in general, exceed two and a half. Hence, to keep them suspended in water, will require a force of only three-fifths of what would be necessary to suspend them in the atmosphere. In the case of river currents, the velocity and irregularity of motion are generally sufficient to keep all the finer sediment equally distributed.

There will, however, be a division of the sediment according to the strength of the currrent. Hence, the bed of a mountain stream, if there is any loose material, always consists of pebbles. As it approaches the alluvial region, the bed is sandy; and when the current becomes very sluggish, it consists of a fine mud.

Rivers never deposit all their sediment, some of them none of it, along their course. Large rivers continue partially distinct from the ocean water to a considerable distance beyond their mouths. The waters of the Amazon have been recognized at a distance of three hundred miles. This depends in part upon the volume and velocity of the river; more, however, upon the fact that river water is lighter than sea water. This extension of a river will, in most cases, be sufficient to deliver a part of its sediment into a marine current. When such a current sweeps very near the mouth of a river, as it does to that of the Niger, the Amazon, or the Mississippi, it is probable that most of its sediment is carried away by it.

The transporting power of a marine current is greater than that of a river, in consequence of the greater specific gravity of its water; but it has scarcely any of that irregular motion of rapid rivers, upon which their transporting power in a great degree depends. The force of the current alone, when it reaches the bottom, is, however, sufficient to remove every form of loose earthy matter. Thus it may be presumed that the Gulf Stream sweeps all the sediment from its bed until it reaches the latitude of Cape Hatteras, where the cold waters from the north begin to underlie it, and it takes the character of a surface stream.

But the transporting power of marine currents depends mostly upon the depth of water. It is found, by experiment, that ordinary river sediment will sink in water about one foot in an hour. A

current, therefore, of a thousand feet in depth, which moves a mile in an hour, would carry its sediment a thousand miles. It is obvious, then, that there is no part of the bed of the sea which may not be receiving sediment.

III. *The Deposition of Sediment.*

From what has been said of the weight of sediment, it follows that it will be deposited whenever the water in which it is suspended is at rest. Hence, when a river increases in breadth so as to form a lake, the waters at the outlet are seldom turbid. The earthy matters with which the principal and tributary streams were charged all settle to the bottom, and go to lessen the capacity of the reservoir. Thus lakes are continually diminishing in depth and area. In many instances, they are already filled with sediment, and are thus converted into alluvial plains, through which the river flows in a narrow channel.

It is frequently the case that a river, as it approaches the sea, has so slow a motion that its sediment is deposited on the bed of the stream. Thus the bed will be raised, and the banks will also be raised, by the deposition of sediment upon them at periods of overflow. The river will then be raised above the adjacent country. The river Po, for the last part of its course, is from ten to twenty feet above the adjacent lands. The same is true of the Mississippi, and many other rivers. The streets of New Orleans are several feet below the surface of the river. In an uninhabited country, such a river would soon seek a new and lower channel; but in a populous country, it becomes a matter of interest and safety to confine the river in its old channel, by artificial embankments.

But the principal part of the sediment of rivers is conveyed to the sea. It here mingles with the debris which the waves have furnished, and a part of it is deposited to form deltas. The remaining part is taken up by marine currents, mingled with the debris which they have furnished, and is spread out on the bed of the ocean.

Of the extent of these deposits we can form no estimate. Those of rivers and lakes are comparatively unimportant, as they are in

the older formations. Some of the delta deposits are already of great extent. That of the Ganges contains an area of twenty-six thousand square miles, that of the Niger twenty-five thousand, and that of the Nile twelve thousand. The delta of the Rhone has increased its area by three hundred square miles in the last thousand years. The Po has encroached upon the Adriatic two thousand square miles in the last two thousand years, and the Mississippi has enlarged its delta by one hundred square miles in the last hundred years. In the deep valleys of the ocean accumulations may be taking place on as large a scale as they ever have been in former times.

IV. *Character of the Formations thus produced.*

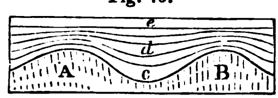
Sedimentary matter thus deposited would take the form of *strata.* Thus, a delta deposit may receive at one time from a river a layer of coarse gravel and pebbles, and in the course of a few hours the current may be so reduced that it will convey to the same place only fine sand and silt. Or, if a depositing current receive its sediment only at intervals, the heaviest particles would be thrown down first, and the more finely levigated particles would continue to fall, till the water became transparent. Another supply would furnish another similar stratum, and so on. The same arrangement might result from the sediment being furnished by different rivers. Thus, if sediment were furnished to the Gulf Stream by the Merrimac river, and the streams emptying into the Bay of Fundy, the freshets would occur earlier in the season in the Merrimac, and it would furnish a supply of sediment from a region of primary rocks. A later supply would come from the red sandstone region of Nova Scotia, and the stratification would be indicated by the different kinds of rock produced. Thus stratification will result from difference in the color, composition, or size of the particles of which rocks consist. A great variety of causes, both general and local, may therefore give to a deposit this character. Hence, as stratified rocks are produced by the sediment now laid down from water, we may conclude that the older stratified rocks are the sediment deposited in like manner, in former times.

The occurrence of layers of different composition, as one way in which the stratification is indicated, is produced by local and frequently recurring causes. There are, however, other alternations of much greater extent; those, for example, nearly twenty in number, distinguished by striking differences in lithological character, into which the New York system of rocks is divided. These alternations have resulted from more general causes. The physical geography of a wide region must have been so different, at the different periods during which these several formations were deposited, as to change, at each period, the kind of sediment furnished to the forming currents, and modify the types of animal life.

We have seen that the same causes that determined the stratified arrangement will determine the alternations of strata of coarse and fine materials.

It is obvious that the stratification of the marine deposits will be nearly horizontal. If the surface were very irregular upon which the deposition commenced, the irregularity would constantly diminish; for the movement of the water over this surface, however slow, would tend to remove the accumulations from the highest points, and leave them at the lowest (Fig. 75). Delta and lake deposits will, however, dip somewhat, though never at a high angle, towards the deep water. In certain situations, where a river and a tidal wave, coming in conflict, cause, in succession, eddies and currents in opposite directions, we should expect to find the stratification very irregular (Fig. 76); sometimes false stratifications (*a b*), sometimes the strata cut off abruptly, and at other times contorted or dipping in opposite directions within short distances.

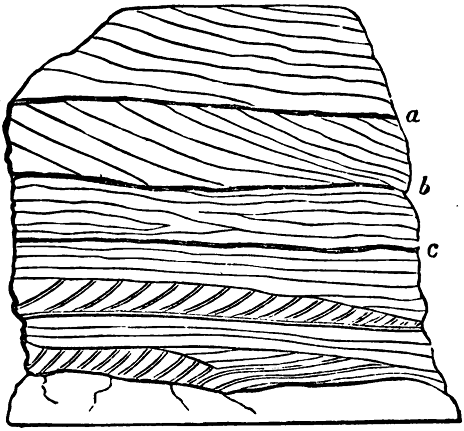
Fig. 75.




Wherever sediment is deposited, it will entomb whatever of the remains of animal or vegetable life may be mingled with it. They will be at once protected against the influence of all the ordinary decomposing agencies, and will continue for ages to retain their peculiar markings, and even their colors. They will thus constitute, in all future time, a record of the present condition of the organic

world. The lacustrine deposits can contain only fresh-water species of animals, marine deposits only marine animals, while deltas may contain the remains of marine life mingled with those which have

Fig. 76.




been washed down by rivers. The remains of birds, insects, and terrestrial animals, may occasionally occur, in every kind of deposit. Sediment deposited in deep water will never contain fossils in abundance, the deep parts of the ocean being almost wholly destitute of animal or vegetable life. It is only in water of a few fathoms that the greater number of species and of individuals occur. In all these particulars the deposits now forming sustain a close resemblance to the older formations.

There are certain formations, as that of the coal, which required conditions for their formation different from those of ordinary sedimentary deposits. Coal consists of mineralized vegetable matter. Its vegetable origin is proved by the uniform occurrence of vegetable fossils almost exclusively in the coal measures. When reduced to thin slices and examined under a high magnifying power, a structure very similar to the ligneous tissue of existing coniferæ is sometimes found to exist. There are probably vegeta-

ble deposits now taking place not altogether unlike those which produced the coal measures.

We know that many rivers — the Mississippi, for example — now carry into the sea great quantities of ligneous matter. Before the country was inhabited by man, the quantity was undoubtedly much greater than it now is. It floats for a time; but the ligneous tissue itself is heavier than water, and as soon as the air is excluded from the pores, and they are filled with water, it will sink. The woody and earthy matters are swept into the sea together; but, as they sink under different circumstances, they will be deposited separately. *Thus wood may continue to accumulate in particular places in the sea* for long periods, with but little intermixture of earthy substances.

It is, however, to be expected that, in the progress of geological changes, the places which at one time receive deposits of wood will at another receive detrital matter, and thus *the wood will become deeply buried* beneath sedimentary strata.

Wood thus situated will become converted into coal. Trees which had been covered to considerable depth with earth have been found near the Mississippi river changed to lignite, a substance resembling charcoal. In this case, the wood had been exposed to no greater heat than is common to the crust of the earth at the depth where it was found; and yet it had undergone this change since the country has been known to Europeans, as it retained the marks of the axe when it was discovered. It has also been found by experiment that vegetable matter, by long submersion in water, passes into the state of lignite. This is the first step in the conversion of wood into mineral coal.

When lignite is exposed to moderate heat and great pressure, it loses the characters of lignite, and becomes mineral coal. This is shown by facts observed in Germany, Ireland and Iceland, where beds of lignite have been overspread by basalt. The upper portions of the lignite are changed to mineral coal. The lower portions, which the heat did not reach, retain the characters of lignite.

Beds of vegetable matter, with a great thickness of rock deposited above them, would therefore be subject to all the conditions necessary to convert them into coal, namely, pressure from the superincumbent mass, and the heat which the strata uniformly assume at great depths.

It is not improbable, therefore, that coal-beds are now forming, and that they have been formed at every geological period since an abundant terrestrial vegetation commenced. Accordingly, there occurs in Virginia an extensive coal-field in the oölite formation. Coal-fields also occur in England, of less extent, in the same formation. In France, and other parts of Europe, there are extensive beds of lignite in the tertiary formation.

We have therefore no difficulty in accounting, in a general way, for the formations of the carboniferous period. The vegetables were probably less woody than those of the present time of equal size, and were therefore more easily prostrated and committed to the waters. They grew rapidly in moist ground, and perhaps in shoal-water, and required an atmosphere charged with moisture and of a high temperature. Thus much is inferred from the conditions most favorable for the growth of recent species analogous to the coal-plants. These recent species are tropical plants, and grow in moist insular situations, — conditions which would have existed at the carboniferous period, if the present coal-fields were then an archipelago dotted with low islands.

Such being regarded as the origin of the coal-beds, the *alternations* of the earthy and carbonaceous strata may be referred, provisionally, to those great changes in physical geography upon which the other alternations of strata on a large scale depend. But the regularity with which the coal-seams and sandstone succeed each other presents some difficulties which, in the present state of knowledge, we cannot satisfactorily account for.

*Beds of salt* occur, interstratified with other rocks, in nearly all countries. Still, it is not a sedimentary deposit, and its formation must depend upon peculiar circumstances. In New York, saline, together with earthy matter, constitutes the Onondaga limestone,

one of the formations of the New York system. In Kentucky, the strata of rock-salt are in the coal formation; in England, they are in the new red sandstone; in Spain, they are in the greensand, and in Poland they are in tertiary strata. The conditions of its formation have therefore existed in connection with the deposition of every fossiliferous rock.

It has been shown that the ocean is the principal reservoir of the saline matters which are taken up whenever water percolates through rocks. It must happen not unfrequently, in the course of submarine elevations, that a basin of sea-water will be cut off from its communication with the sea; and from this basin the evaporation might be more rapid than the supply of water. The great salt-lake of Utah is undoubtedly a basin of this kind. The Mediterranean Sea is another such basin, not yet wholly separated from the ocean. The evaporation exceeds the supply of water from the rivers, and a powerful stream is therefore continually thrown in from the ocean, through the Strait of Gibraltar. The waters of the Mediterranean are already more highly charged with salt than ordinary sea-water. This sea may ultimately become a saturated solution, and begin to deposit salt. But whether it does, or not, it indicates the way in which salt-beds may be formed.

V. *Solidification of Aqueous Deposits.*

Sediment is generally deposited as a soft mud, but in nearly all the older formations it has become solidified. When rocks are deposited from a chemical solution, they take at once the solid form. Such is the case with rock-salt and with limestone, when the material has been held in solution. Solidification takes place in nearly the same way when water which holds carbonate of lime or oxide of iron in solution filters through beds of sand or gravel. The substance held in solution is deposited in the interstices till they become filled, and the whole is changed to solid rock.

Some rocks are composed of such materials that they *set*, like hydraulic cement, when they are deposited. Other rocks become solid simply by drying. Thus a deposit now forming in Lake Superior becomes, by drying, nearly as hard as granite. Such a

deposit will therefore become solid whenever it shall be elevated above the water.

The pressure to which all but the upper layers are subjected is probably sufficient to reduce most rocks to the solid state. Dry and pulverized clay is reduced by artificial pressure, for a moment, almost to stone. The pressure upon the deep-seated rocks is constant, and greater than any artificial pressure can be.

In addition to these causes, all the older rocks have been subjected to a high temperature, some of them nearly to that of fusion. By this means the solidification of every kind of rock would be promoted, and probably some may have been reduced by it to the solid state, which would otherwise have remained as an incoherent mass.

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## SECTION V. — AQUEO-GLACIAL ACTION.

1. *Glaciers.* — A glacier is a mass of ice occupying the bed of a mountain valley, having a slow progressive motion, and reaching somewhat lower in the valley than the line of constant snow. (Fig. 77.) The Glacier des Bois, which may be regarded as a specimen of the Alpine glaciers, covers an area of about seventeen square miles. In its lowest portion, when all its branches have become united into one stream, it has an average width of half a mile, and is five miles long. It is estimated that the glaciers of the Alps cover an area of fourteen hundred square miles. These have been the most carefully studied, though glaciers are found in the valleys of various other ranges of mountains.

In the higher valleys, the snow, which falls at all seasons of the year, accumulates in immense quantities, and the steep mountain sides contribute, by frequent avalanches, to this accumulation. The snow, when thus increased, does not become a compact, adhesive mass; but, changing into particles of solid ice, it resembles sand rather than snow. It is this *névé* which constitutes the upper part of every *glacier*, and which, in a modified form, constitutes the lower part.

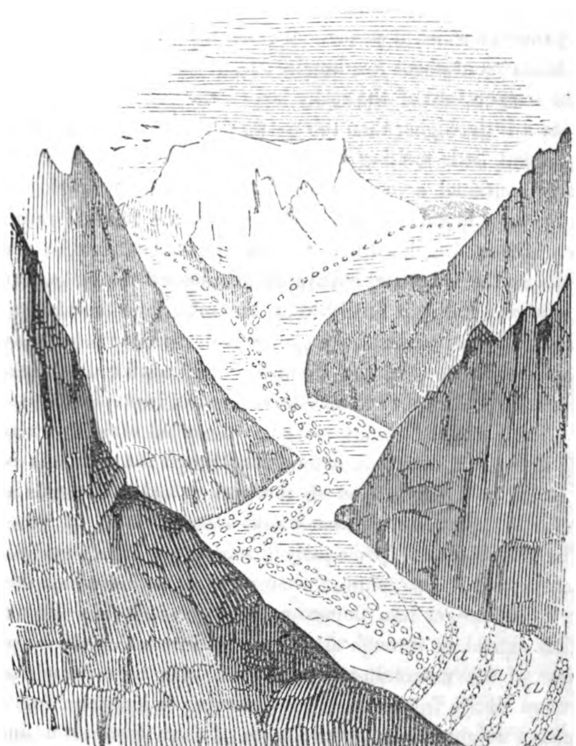
The valleys descend rapidly towards the base of the mountains; and this snow-ice, having no cohesion between its particles, *moves slowly down the slope of the valley*, like a very imperfect liquid. After descending below the line of perpetual snow, the surface will melt during the day; and the water, sinking into the porous mass, becomes frozen, and converts the whole into more or less compact ice, yet never into a rigid mass. Influenced by its own weight, and by the pressure of the snow-ice behind, it still continues its motion, and conforms itself to the shape and curves of the valley through which it passes. The average movement per annum may be stated at about five hundred feet.

The temperature of the rocky bed of the valley will be a little, and but a little, higher than thirty-two degrees. There will therefore be but little melting at the bed of this river of ice. As it receives continual accessions from the atmosphere, it will therefore increase in volume till it descends to the level of perpetual snow. Below this line *the waste exceeds the addition;* and as it approaches the lower and cultivated portions of the valley, it rapidly diminishes, till it finally loses the solid form, and becomes a rivulet. The terminus of the glacier is determined principally by the general climate of the country. Any considerable variation of climate will cause it to recede, or descend lower down the valley. The terminus varies, however, somewhat with the seasons, being lower in winter than in summer, though the motion is much less in the cold season than in the warm; and it descends many rods further some seasons than it does others.

The glacier consists principally of snow, more or less modified in structure; but it also contains whatever else may have been thrown upon its surface, or into the snows by which it is fed. Tributary glaciers extend up through all the gorges into which the irregular surface of the mountain-top is divided. On these rough peaks there are always fragments of rock, varying in size from fine sand to masses weighing many tons; some of them loosened when the mountain was upheaved, some by subsequent earthquake vibrations, and others still by tempests, lightnings, and changes of

temperature. When the snow has accumulated to a certain extent on the steep slopes, it falls in avalanches into the valleys, carrying with it loosened masses of rock, and often breaking off large fragments from the rocky escarpments against which it strikes. These avalanches are almost constantly descending, and hence a glacier always contains considerable *earthy matter distributed through it.*

Fig. 77.




The friction of the glacier, at its edges and along its bed, separates more or less of the rock over which it moves; and hence

there is always a layer of mud and pebbles under the glacier, and a line of loose fragments, called a *lateral moraine*, at the sides. When two glaciers unite, the two lateral moraines, thus brought together, come to the surface, forming a medial moraine, and show the line of junction sometimes for miles.

The friction of the glacier on the bed of rock, assisted by the layer of pebbles, will wear down the prominent portions, and everywhere polish the surface. Fragments of rocks may be frozen into the glacier at all depths. Those which lie near the lower surface of the glacier would, by slight melting of that surface, project downward so as to act as a graver's tool on the rock over which it passes. Hence, when the extremity of the glacier has receded beyond its ordinary limit, the surface of rock exposed is found, upon examination, to be *polished*, *striated*, and *occasionally grooved* an inch or two deep.

Since the waste is almost wholly superficial, earthy matter, which was at first concealed in the mass of the glacier, is continually coming to view, as the surface melts and runs off. Thus, none of the freight of the glacier is left along its course, but all is carried to its terminus and discharged there. Hence, at the lower extremity of the glacier there is always an embankment of earth, pebbles, and boulders. If the glacier recedes a few yards at one season of the year, and leaves its earthy fragments scattered over this surface, they will be pushed forward into a ridge, as the glacier again advances. This ridge is called a *terminal moraine*, and consists wholly of substances which have been separated from the mountain mass, often at the highest beginnings of the glacier. At the terminus of all the Alpine glaciers, there is a series of these moraines (*a a a*, Fig. 77) marking the successive limits of the glacier in former times.

There is a ridge of boulders on the north side of the Swiss valley, near the base of the Jura Mountains, resembling a terminal moraine. These boulders consist of several groups, distinguished by peculiarities of structure and composition; and each group lies opposite to the particular Alpine valley which now furnishes the

same kind of fragments. It has been thought that, at a former period of more severe climate, the Swiss valley was filled in part with ice, and that the present glaciers extended across it to the Jura Mountains.

It is found that the polished and striated surfaces of the rocks in the Alpine valleys are precisely like the surface of the rock, which has not been exposed to atmospheric influences, in the north of Europe and America. It has been proposed to extend the glacier theory, and account for these phenomena by supposing that the north polar regions were, at the ice period, capped with a glacier-mass, extending as far south as the drift phenomena appear.

It is not to be doubted that the phenomena of polished surfaces and transported materials in the immediate vicinity of the Alps, and near other high mountains, are correctly referred to glacial action. This theory has therefore solved, in part, one of the most difficult problems in geology; but there is great difficulty in extending it so as to account for the drift phenomena in general. If the motion depends upon gravitation only, the origin must have a much greater elevation than the terminus, which would not be the case in the great glacier supposed to extend southward from the Arctic regions. Elevation of temperature, it has been thought, might account for the movement of the mass southward.

2. *Icebergs.* — In very high latitudes, the ice, which makes out from the land into the sea during the cold season, suffers but little waste at any time. This sheet of ice continues to increase in breadth and thickness, by congelation, from year to year. The spray and the snows of each succeeding year will also add to the mass. It thus accumulates to the height of several hundred yards. It will also reach down a good many feet below the surface of the sea, and will extend back on the land, or lie heaped up against a precipitous escarpment, and firmly frozen to it.

After a certain amount of extension over the sea, the accumulated weight of the ice and snow would tend to depress it, and break it loose from the shore. The waves would tend to the same

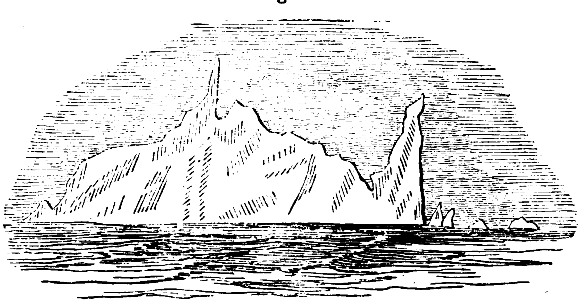
result, and would act at greater mechanical advantage, as its extension from the shore becomes greater. *Hence, it would ultimately become separated from the shore*, and float in the water.

At its commencement, the earth, pebbles and rocks, which may lie along the shore, and as far down into the sea as the congelation extends, are frozen into it. In many situations its mass would be increased by avalanches while it remained attached to the land, and these would supply also masses of earth and rocks, as they do to glaciers. When it becomes loosened from the shore, it will break off, and carry with it some of the earthy portions of the coast, or the less firmly fixed masses of rock from the escarpment against which it formed. Thus every iceberg becomes *freighted*, more or less, *with earth and rocks*. This has almost uniformly been found to be the case, when they have been landed upon by ships' crews and examined.

We have seen that the general tendency of the waters of the ocean, and of the lower stratum of the atmosphere, is to a motion from the poles towards the equator. However irregular, therefore, the course of an iceberg may be, its general *movement*, influenced both by the prevailing winds and by ocean currents, will be *towards the equator*.

These floating ice-mountains (Fig. 78) are formed in *great num-*

Fig. 78.



*bers, and of vast size.* The relative specific gravity of ice and water are such that nine cubic feet of ice, below the surface of

water, will support one cubic foot above it. As icebergs are often one or two hundred feet high, their vertical depth must be a thousand feet at least; and their area is equal to a square mile, and sometimes it is much greater. In 1840, the United States Exploring Expedition, in the extreme southern ocean, coasted for eighty miles along a single iceberg. They are never absent from the polar seas; and at certain seasons they are so abundant along the usual course of vessels from New York to Liverpool, as greatly to obstruct and endanger navigation.

An iceberg may continue for some time to increase in size, while floating in the polar seas, but will at length reach a latitude where the waste will exceed the additions, in consequence of the temperature both of the air and of the water. It will, therefore, drop gradually the earthy matters which it contains, upon the bed of the ocean.

It is not improbable that icebergs may often reach down so far as to strike the highest points of the bed of the sea. The ice would be lifted, and glide over the elevation, without suffering any perceptible deviation from its general course. It would thus affect the surface of rocks exactly like a glacier. If, however, the iceberg becomes permanently stranded, and melts in one place, its earthy matters will be thrown down upon the elevation which first arrested it.

If the bed of the sea, between the fortieth and sixtieth degrees of latitude, could be exposed for examination, the rocky surface would be found to be polished and striated by the icebergs which have passed over it, and the whole surface would be strewed with boulders and drifted materials brought from Arctic and Antarctic lands. Sometimes it would be accumulated in heaps, and sometimes spread nearly over the surface.

We have seen that very recently, probably about the close of the tertiary period, the portion of Europe and America over which the northern drift is found, has been depressed several hundred feet. It may be presumed that at that time icebergs floated over it, polished the surface of the rocks, and distributed the boulders and other drift which is now found upon it.

## SECTION VI. — IGNEOUS CAUSES.

I. *Of the Temperature of the Mass of the Earth.*—Heat has been the most efficient agent in determining and modifying the structure of the earth; and, in order that the explanations of the phenomena referable to this cause may be intelligible, some idea must be formed of the actual present condition of the mass of the earth with respect to heat.

At any point of the surface there are variations of temperature, depending on external causes. But these variations are found to extend only a little way below the surface,—never more than a hundred feet. At greater depths, it is found that the temperature invariably increases with the depth. Deep mines have always a temperature above the mean annual temperature at the surface. The water obtained by deep boring is always tepid when it comes to the surface. The thermal springs, so abundant in this country and in Europe, are so situated as to justify the impression that their waters come from great depths. To make these general observations of any value, we must determine the law by which the temperature increases. The result of all the observations yet made, in mines and upon wells and springs, is that, below the first hundred feet, the temperature increases by one degree of Fahrenheit's scale for every forty-five feet.

Regarding this law of increment as applicable to all depths, at ten miles below the surface we should have a temperature above that produced by the combustion of wood; and at twenty-five miles, a temperature of three thousand degrees, by which nearly all mineral substances would be reduced to a state of fusion.

The general conclusion of a temperature sufficient to melt the mineral substances of which rocks are composed, at no considerable distance below the surface, is confirmed by the fact that portions of the interior of the earth — at least, at the volcanic centres — are in a melted state. The intimate connection between some volcanoes situated a hundred miles or more apart, so that they are alternately in a state of activity and rest, indicates that these centres are con-

nected, — that subterranean melted lava extends from one to the other, so that when one is active, the elastic force is relieved at the other. These deep-seated lakes of lava must therefore underlie large areas.

We are justified, then, in concluding that the mass of the earth, with the exception of a comparatively thin superficial layer, has a very high temperature.

By way of accounting for this temperature, it is now generally assumed that the earth was originally in a state of fusion; that it was a mass of liquid lava (if, indeed, it had not a temperature sufficient to reduce it to the aëriform state). Starting with this assumption, there must necessarily be a gradual reduction of temperature by radiation, and a time must arrive when the surface would be crusted over with solidified lava; and this crust would increase in thickness as the cooling advanced, the interior still retaining its heat and liquidity. The present condition of the crust of the earth, its form, that of an oblate spheroid, with the exact difference of the equatorial and polar diameters which is found to exist, as well as the phenomena of volcanic eruptions, will all admit of explanation on this hypothesis.

It has, however, been rejected by some; and, to account for the heat of the interior of the earth, it is suggested that, if the bases of the earths and alkalies, particularly potassium, sodium and calcium, exist in their metallic state beneath the surface, the rapid oxidation of them by the access of water would generate heat of sufficient intensity to melt the oxidized materials, and thus account for the phenomena attributable to heat.

Either of these hypotheses may be adopted; but it is not necessary to account at all for the existence of this temperature. The fact is susceptible of proof; and, though we may not be able to frame any hypothesis to account for its existence, we may yet employ the fact in the explanation of other phenomena.

II. *The Action of Internal Heat in producing Volcanoes.*

The phenomena of volcanoes and earthquakes are evidently produced by some force operating from below. The effect of heat

alone would be to reduce the rock to a liquid state. There is no reason to suppose that it is ever sufficient to reduce them to the aëriform state. The elastic force must therefore depend upon some other substance associated with the lava, and this substance is water.

This will be shown by an examination of lavas. At the time of their ejection, they are in a fluid or semi-fluid state; but it is not a complete fusion. Even the most fluid lavas contain particles of minerals in a solid state. The liquidity depends upon the fusion of the more fusible portions, and upon the steam of water at a high temperature, which fills the interstices between the solid particles. The porous character of cooled lavas is produced by the steam which filled the cavities previous to solidification. Steam always escapes from the surface of a lava current while it is cooling, and it is always discharged in immense volumes from the orifice of eruption, in connection with the lava, and especially at the close of an eruption.

The geographical position of volcanoes, also, leads to the conclusion that water is essential to their activity. There are five principal lines of volcanic activity. One, commencing at the southern extremity of South America, extends northward along the Andes and Cordilleras to California or Oregon. The second has a north-east and south-west direction, from the Aleutian Islands through the Kurule, Japanese, and Philippine islands, till it meets the third line, lying in a nearly east and west direction, embracing Sumatra, Java, and most of the Pacific volcanic islands. A fourth band commences in the Grecian islands, and extends westward so as to include the volcanoes of Italy and the adjacent islands, and the Azores. The fifth band embraces the volcanic islands of the West Indies, crosses Mexico in about the latitude of the city of Mexico, and extends into the Pacific. There are also some isolated centres of volcanic activity, such as Iceland. These volcanic bands embrace about three hundred volcanoes. It will be seen that they must nearly all be in close proximity to the ocean, or to large seas. About two-thirds of them are on islands.

Moreover, the volcanic vents which are wholly submarine are probably very numerous.

This circumstance of the position of volcanoes establishes a presumption that they cannot exist at a distance from some large body of water; and, taking it in connection with the constant presence of aqueous vapor in lava, we are justified in the conclusion that *the presence of water is an essential condition of volcanic activity.*

Knowing that heat and water exist at the volcanic centres, it is not difficult to form an idea of *their mode of operation.* The water, diffused through the interstices of the lava, and subjected to a temperature sufficient to melt the lava, would possess an *elastic power*, which, though never computed, we may well suppose capable of overcoming any resistance which the crust of the earth might present. The repressing force will be the tenacity and weight of the superincumbent strata. Whenever the elasticity is superior to this repressing force, it will manifest itself in the fracture of the strata, and often in the ejection of lava to the surface.

This fracturing of the strata, produced by an uplifting subterranean force, is believed to be the cause of the noise and the vibratory motion which are the chief phenomena of earthquakes. The elastic force may raise lava to the surface, and thus the fracture would become a volcano. But the force may expend itself by the discharge of vapor into the fissure, or by merely filling it with lava. In either case, the only evidence of the existence of the volcanic force would be the noise and the wave-like motion experienced at the surface. The cause of the volcano and earthquake is therefore the same, though the phenomena which characterize them are different.

When the strata are is thus fractured, lava may for a time be discharged along the whole line. By the cooling of lava in the fracture, it would become partially reünited. Still, this would be the line of least resistance. It would therefore be again burst through in certain places, which would long continue to be orifices

of discharge, and thus the original fracture would determine *a line of volcanic activity.*

The repressing force may become greater at an orifice of eruption than at some other point, either by the great accumulation of ejected materials around the opening, or by the dormancy of the volcano long enough for the complete solidification of the lava with which the channel was filled. The least resistance may then be far from any previous vent, when a new orifice of discharge will be opened, and *a new volcano make its appearance.* It seems probable, also, that volcanoes may become extinct by the reduction of temperature at the volcanic centre, and that new volcanic centres may be formed; but the cause of this change of temperature is not yet well understood. New volcanoes have broken out in the sea, near Iceland, in several instances; others in the volcanic line east of Asia. Graham Island, situated between Sicily and Africa, was formed by an eruption which broke out in the bed of the sea where the soundings were more than one hundred fathoms. The island was at one time two hundred feet above the sea, and three miles in circumference. It was, however, gradually destroyed by the action of the waves, and now remains a dangerous reef, covered by less than two fathoms water. The volcano of Jorullo, in Mexico, was formed in this way. Previous to the formation of the mountain, the region where it now is was a cultivated table-land. During the year 1759 volcanic action commenced and continued, until, at the expiration of twelve months, a cone had been formed having an elevation of sixteen hundred feet above the adjacent plain.

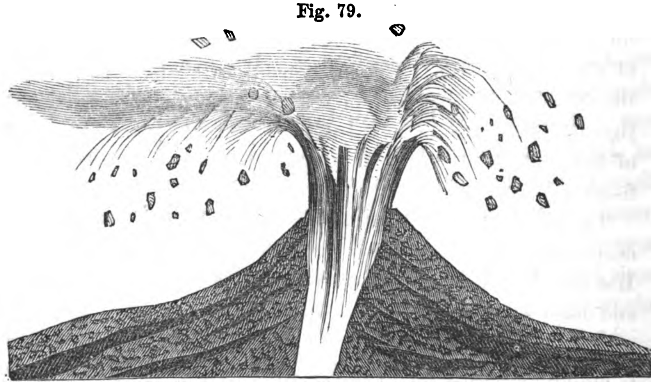
An orifice of eruption is at first but little elevated above the general surface; but, by the accumulation of ejected matter, a *cone* is at length formed around the vent. The upper portion of a cone always consists of these materials, but there may also be in progress a general elevation of that part of the earth's crust, and the cone will partake of that general elevation. The cones of the Andes owe their height, in a great measure, to a general movement

of elevation; those of Ætna and Vesuvius, in a greater degree, to accumulation of ejected matter.

In either way, the height may become so great that the force necessary to raise a column of lava to the top would be greater than the sides of the cone, weakened as they always are by fractures in all directions, can sustain. Hence, the highest craters of Ætna and South America have long been closed, and the lava escapes through fissures at a lower level, and *lateral cones* are produced.

The form which the materials have, when ejected from volcanoes, depends mainly upon the degree of liquidity of the lavas at the volcanic foci. If the liquidity is very perfect, the aqueous vapor will readily rise through the lava. The steam thus separated will drive before it whatever rocks, or previous lavas, may obstruct it. In their progress they would be reduced to sand and powder, and ejected as *volcanic cinders.* (Fig. 79.) If the lava

Fig. 79.



possess considerable viscidity, the aqueous vapor will separate with more difficulty, and the lava and vapor will ascend the channel together. Large bubbles of vapor will, however, collect with more or less of frequency; and, as they rise through the lava, will drive forward a portion of it, and cause the overflow to take place by pulsations. As the bubbles reach the surface, their burst-

ing causes the loud reports, which are compared to the discharge of heavy artillery. With each explosion some of the lava will be projected violently into the air, and, cooling, will fall to the surface as *scoriæ*, — or, if the lava be highly vitreous, it will be drawn out into fibres, and descend as *volcanic glass*.

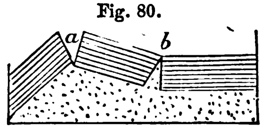
III. *Geological Phenomena referable to Volcanic Action.*

Volcanic agency has probably never been less than it is now, and we ought therefore to find its effects very general and important.

1. The most obvious of these effects are the *fractures* with which the crust of the earth is everywhere intersected. The uplifting force upon which all volcanic phenomena depend would necessarily fracture the crust, and the wave-like motion resulting from the fracture would cause numerous secondary fractures, having a parallel direction. They are often of such extent, during earthquakes, as to endanger life. During the great earthquake at Lisbon, in 1755, a fracture opened of sufficient width to swallow up the quay, and several thousands of persons who had fled there for safety. The chasm remained permanently open to the depth of six hundred feet. The earthquakes with which the valley of the Mississippi was visited in 1811 so often fissured the surface, that the inhabitants protected themselves by clinging to the trunks of trees, which they felled transversely to the direction of the fissures.

The first fracture which is produced by the upheaving force will open upwards, and scarcely reach down to the seat of the force. But there will be other parallel fractures, dependent upon the first, and opening downward. Thus, the primary fracture at *a* (Fig. 80) will be at once followed by the fracture *b*, opening toward the lava, which will be injected into it, and which, on cooling, will form a *dike*. Their formation is mostly concealed from observation, but not always. During the eruption of Ætna, in 1669, numerous fissures opened, one of which was six feet wide and twelve miles in length; and the light emitted from it indicated

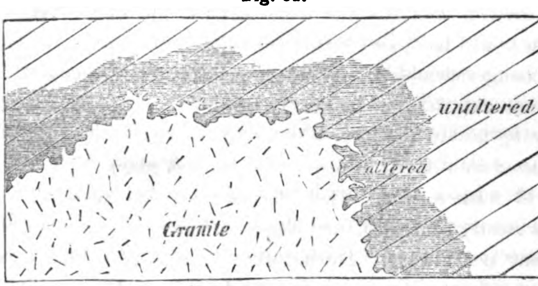
Fig. 80.



that it was filled with lava to near the surface. The process was as perfectly seen as from the nature of the case it could be.

2. The conversion of the lower sedimentary strata into *metamorphic rocks* has been effected by volcanic heat. The material of which dikes consist has been injected in a highly-heated state; and, by observing the effect which they have had upon the adjacent rocks, we may judge of the effect which subterranean heat must have upon the lower mechanical strata. Wherever the dikes are of considerable thickness, they have converted the adjacent shales into primary slate, the sandstones into quartz rock, and the dark and friable limestones into granular marble, and destroyed the organic impressions. In the southern extremity of Norway there is a district in which granite protrudes in a large mass through fossiliferous strata. These strata are invariably *altered* to a distance of from fifty to four hundred yards from the granite. The shales have become flinty, and resemble jasper; and near the granite they contain hornblende. The siliceous matter of the shales has become quartz rock, which sometimes contains hornblende and mica, and therefore constitutes a kind of granite. The limestone, which at points remote from the injected rock is an earthy, blue, coralline limestone, has become a white, granular marble, near the granite, and the corals are obliterated. The altered shales and limestones in many places contain garnets, ores

Fig. 81.




of iron, lead, &c. The annexed (Fig. 81) is a plan of this granite and altered rock.

One of the most instructive examples of metamorphic action in this country is found in the White Mountains of New Hampshire. These mountains have, till recently, been thought to consist principally of granite; but it is now ascertained that this supposed granite is an altered rock of the silurian period. It is represented as "intersected by veins of felspathic granite; and the general mass is itself in many parts converted into a near approximation to a binary granite, composed of distinctly developed quartz and white felspar, with a few sparsely scattered specks of mica. In its weathered surfaces it wears a close resemblance to some fine-grained granites; but, upon inspecting a fresh fracture with a magnifier, we instantly perceive many rounded grains of quartzose sand, and the felspar is imperfectly formed, though the mica has more nearly reached the condition which it has in granite. In some of the coarse varieties of this white rock, small rounded pebbles of quartz are to be seen, giving unequivocal evidence, even to the naked eye, of its being an altered sandstone. We feel no hesitation in deciding it to have been a silico-argillaceous white sandstone, now almost granitized by extensive metamorphic action."

Similar illustrations, on a small scale, may be seen in every country where the strata have been cut through by intrusive dikes. Sir James Hall has shown the same by actual experiment. He exposed pulverized chalk to heat sufficient to melt it, and under sufficient pressure to prevent the escape of the carbonic acid. After cooling, the chalk was found to have taken the form of crystallized limestone. But instances enough have been given to show what changes should be looked for wherever the sedimentary rocks have been exposed to a high temperature.

The lower strata must have been exposed, for long periods of time, to such a temperature. We do not know at what depth below the surface of the earth the rocks become liquid; but above the line of actual fusion there must be a mass of rock not melted, yet scarcely retaining the solid form. For a great thickness, perhaps for several miles, it would be in a more or less yielding state. As there is not actual fusion, the stratification is not destroyed,

but such a degree of mobility among the particles exists, that some degree of crystallization takes place, and the elastic forces below easily bend, throw into folds, compress, and in every way contort these strata. At the same time, any organic matters which they may contain are decomposed, and the impressions of them are obliterated. And such is the condition in which the metamorphic strata are actually found.

3. *Denudation* is, in a great measure, dependent on volcanic action. It results from the billowy motion peculiar to the earthquake. This is not simply a violent horizontal motion, but an equally violent vertical one. It is a series of waves, — a succession of alternate elevations and depressions of the solid crust. The height of these waves can only be judged of by their effects; but it is difficult to account for some of these effects, without supposing the waves to have been several yards in height, and their velocity, in the few instances in which the time has been accurately determined, was twenty miles a minute.

That such earthquake waves actually exist there can be no doubt. During the earthquake in Calabria, in 1783, the flagstones in many of the towns were lifted from their places and thrown down inverted, and trees bent so that their tops touched the ground. During the great earthquake in Chili, in 1835, the walls of houses, which were parallel to the line of oscillation, were thrown down, while those that were at right angles to it, though greatly fractured, were often left standing. Wherever careful observations have been made, during and after severe earthquakes, analogous facts have been noticed. Persons are generally affected with sea-sickness. The sea is violently agitated. It often retires to an unusual distance, and then returns upon the shore with most destructive waves. Incredible, therefore, as it may seem, that the solid crust of the earth should be thrown into such wave-like undulations, the fact is well established.

With a velocity of twenty miles an hour, the successive waves may be some miles apart, and yet be sufficient to account for all the phenomena. It is evident, therefore, that the curvature of the

wave will be very slight, and yet enough to break into fragments all the rocks thus curved. During the earthquake in Chili, before referred to, "the ground was fissured, in many parts, in north and south lines. Some of the fissures near the cliffs were a yard wide. Many enormous masses had fallen on the beach. The effect of the vibrations on the hard primary slates was still more curious. The superficial parts of some narrow ridges were as completely shivered as if they had been blasted by gunpowder." Similar phenomena seem everywhere to be exhibited by earthquakes.

It may be presumed that almost all parts of the earth have, at different periods, been subject to these earthquake waves. Accordingly, we find that the crust of the earth is nowhere in an entire state, but is divided by irregular lines into comparatively small fragments. By this means, the deep fissures produced by fractures opening upwards would be filled with fragments of rock shattered from the uplifted edges. In this way the boulder masses were originally loosened from their parent beds, and exposed to the action of ice, or any other transporting agencies. In the same way the rocky bed of the ocean is, to a considerable depth, reduced to a disintegrated mass. In this condition it will be rapidly removed by marine currents, more or less broken, worn and comminuted, by the movement, and deposited elsewhere. The materials have thus been furnished for a very large proportion of the sedimentary rocks, and especially of those which are composed of distinct fragments of other rocks. By this means, also, wherever the rock formations come to the surface, they are so broken that limestone, sandstone or granite, suitable for architectural purposes, is seldom found, except at considerable depths. This fragmentary condition of the surface rock is such as exposes it to be acted upon readily by any powerfully abrading causes, or to be more rapidly disintegrated by atmospheric and aqueous causes.

4. We have already assumed that one principal division of rocks — the unstratified — is of igneous origin. We have the proof of actual observation, that *lavas*, and the accompanying *tufas* and

*grits*, are volcanic products. The peculiarities of these products, in situation, structure, and form, and in the imbedded minerals, are so great, that whenever we find these peculiarities in the rocks of a country not now volcanic, we still regard these rocks as of volcanic origin. We thus have lavas, as well as stratified rocks, of different ages. There has probably been no time in the earth's history when they have not been forming.

The *trappean rocks* are also of igneous origin. It is evident, from their occurring in the form of dikes, that they have been in a melted state. As they rest upon rocks of a sedimentary origin, they must have been thrown up by volcanic forces. Yet they differ from ordinary lavas. They are not vesicular in their structure, are more crystalline, and there is in no case evidence that they have flowed from craters. If we regard them as the lavas of submarine volcanoes, we shall have conditions which will account for all their peculiarities. At a certain depth the pressure of the water would be sufficient to prevent the formation and escape of vapor, and therefore the lavas thus ejected would not be vesicular. As the rapid cooling of lavas depends, in a great degree, upon the escape of watery vapor, submarine lavas would cool slowly, in consequence of the pressure. The liquidity depending in part upon the retention of the heat, and in part upon the retention of the aqueous vapor, they would consequently remain in a liquid state much longer than the lavas of sub-aërial volcanoes. They would therefore take a more highly crystalline form. All the loose materials thrown out during the eruption would be removed by oceanic currents, and hence no cone would be built up around the orifice of eruption. We may therefore regard the trappean rocks as the lavas of submarine volcanoes. The present volcanoes of this kind are necessarily producing the same kind of rocks, though there will be no other proof that they exist, except the existence of the volcano, till the bed of the sea becomes dry land.

The *granitic rocks* are also the product of igneous causes. Granite is the most abundant of these crystalline rocks; and the others, such as crystalline limestone, are so intimately associated

with granite that they must have had the same origin. Granite is everywhere found to send off dikes into the overlying rocks, and must therefore have been in a state of fusion; that is, it must have existed as lava beneath the surface. It is obvious that fluid lava always exists in great quantity beneath areas of energetic volcanic activity.

Portions of this lava must in succession take the solid form. Wherever the surface is elevated along a line of fracture, the lava which is accumulated beneath rises above the level of the general reservoir of lava, and will therefore part with its heat more rapidly. On cooling, it becomes the granitic nucleus of the mountain. We ought also to suppose that, by the extremely slow process of the transmission of heat to the surface, the crust of the earth is everywhere increasing in thickness; that is, the upper portion of the great lava mass is solidifying.

Sir James Hall has shown, by experiment, that earthy substances, reduced to a state of fusion, become more highly crystalline as they are allowed to cool more slowly, and are subjected to greater pressure. It is difficult to conceive of these conditions existing in a higher degree than they do in the cooling masses of lava below the stratified rocks. These lavas must therefore take the highly crystalline form which the granitic rocks are found to have.

All the igneous rocks have therefore existed as subterranean lavas. The volcanic rocks have become vitreous, the granitic are crystalline, and the trappean are intermediate in structure, coinciding with the circumstances of pressure and rate of cooling under which they have severally been formed.

5. *The Elevation of Mountains* is another result of volcanic action. The height of mountains depends, in part, upon general elevation. Yet there is a different action, upon which the existence of the mountain, as such, depends. Whenever igneous action becomes intense under any portion of the earth's surface, and the elastic force greater than the repressive, the solid crust will be broken and raised up, and along this line of fracture the lava will rise above its general level elsewhere. This lava, thus lifted out of

the general mass, in time solidifies, and forms the nucleus of a mountain. At successive periods the elevating force is renewed, and adds somewhat to the mountain mass before supplied. In this way the mountain is ultimately formed.

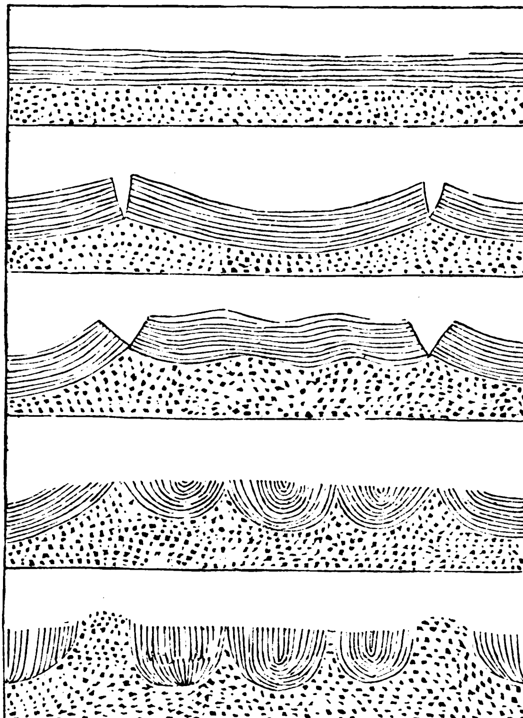
So far as observations have been made, the elevation of mountains seems not to be gradual, but spasmodic; and yet the elevating force probably accumulates constantly and uniformly. The repressing force consists of the weight of the strata above, which may be regarded as constant, and their strength, which is variable. When the elevating force becomes greater than both the repressing forces, the crust is fractured. The strength of the strata then becomes nothing, and the repressing force is the weight alone. The elastic mass below at once expands, and the requisite space is furnished by the uplifting of the strata along the line of fracture. As the ridge of lava which fills this additional space cools, it recloses, in part, the original fracture, and the repressing force again consists of the two elements, — weight and strength. There will therefore be no further elevation till the elevating force is again superior to these two forces. Thus the elevating force, though it may accumulate at a uniform rate, will manifest itself only at considerable intervals.

As the accumulation of lava along the line of fracture is the cause of the upheaval, every mountain must have a central granitic axis. Sometimes this granitic mass is pushed up through the fissure, as in the case of Mont Blanc. At other times, the stratified rock, which formed the original surface, is carried up so as to form the surface rock nearly to the top. In either case, the strata are lifted along the line of fracture, and left in an *inclined position.* In this position the older rocks are always found, wherever there has been any considerable amount of igneous disturbance.

In some instances, the additional space required by the expansion of the igneous mass below is furnished, not by the uplifting of the strata, but by their compression into folds between two lines of upheaval. The igneous rock is elevated but little above the stratified through which it had burst; but the stratified rocks have taken the undulatory form, and the widening of the igneous mass

along the lines of fracture has compressed the undulations, until the planes of *the strata have become vertical.* Fig. 82 will give an idea of the successive changes by which the vertical position of the strata has been produced.

Fig. 82.



The force by which mountains are elevated being the elasticity of the vapor diffused through the subjacent lava, it may happen, if the lava have a high degree of fluidity, that this vapor will collect in large masses, and rise as far as the lava is in a fluid state. The irregular

flow of lava from craters during an eruption is undoubtedly due to the rapid ascent of such steam bubbles through the lava. Such an accumulation of vapor under a mountain mass, if it cannot escape, would support it as long as the temperature remained unchanged. But, upon a reduction of temperature, the mass which had been upheaved by it would be unsupported, and liable at any time to sink. Instances of *subsidence* on a comparatively small scale will admit of explanation in this way. Papandayang, one of the loftiest volcanic mountains of Java, sunk down four thousand feet in the year 1772. The area engulfed was sixteen miles long and six broad. The crater of Kilauea, in one of the Sandwich Islands, was evidently formed in this way. It is situated on the side of a mountain, and consists of a chasm eight miles in circumference and a thousand feet in depth. Liquid lava can always be seen boiling in the small craters at the bottom; and at times it rises so as to overflow them, and fill the chasm to within four hundred feet of the top, when lateral subterranean passages are opened, by which it is discharged. The same explanation — a depression of the central portion — may be given of the formation of the large craters in the Canary and Grecian islands. It is also probable that Lake Avernus and others, in Italy, and some in Germany, have had a similar origin.

The subsidence of Papandayang is of importance as a historical fact; and it is not at all unreasonable to suppose that larger chasms of great depth were also sudden subsidences of a similar character. Lake Superior has a depth considerably greater than the elevation of its surface above the level of the sea. The bottom of the Dead Sea is two thousand six hundred feet below the surface of the Mediterranean. And at one place in the Atlantic Ocean a sounding was attempted with more than six miles of line, without reaching bottom. These sunken areas, however, though of great extent, occupy only an insignificant portion of the entire surface of the earth.

6. *The Elevation of Continents.* — The causes of change of level which have been given will not explain those *slow vertical*

*movements* which are now taking place in Greenland and the north of Europe, or those by which the present continents have been elevated and the bed of the sea depressed. Any cause which will account for these movements must be one operating for long periods, under large areas, and with great uniformity.

The cause which fulfils all these conditions most satisfactorily is a *variation of temperature* in the mass of rock underlying the portion of the surface whose level is changing. It has before been shown that the temperature increases as we descend below the surface; but there is also reason to suppose that it undergoes great variations. The volcanic grits interstratified with the silurian rocks of England show that at the silurian period volcanic fires were active below that portion of the surface. When the early fossiliferous rocks of this country were deposited, the Alleghany Mountains had not been elevated; but before the tertiary period they had taken nearly their present form. Some portion of the intermediate period was therefore one of volcanic upheaval. The trappean rocks are also evidence of intense volcanic action existing here. France, during the tertiary period, was a highly volcanic country; but all volcanic activity has now subsided. The Andes have been mostly elevated since the tertiary period, and are still rising. It is evident, then, that at different periods volcanic heat may vary from its highest to its least degree of activity, below any portion of the earth's surface.

This variation of temperature must be followed by variation of volume of the earth's crust; that is, it *must produce expansion or contraction.* Experiments have been made, under the direction of the United States government, to determine the expansion of the several kinds of rock used in our public works. It was found that granite expands nearly one two hundred thousandth of its length for every degree of increased temperature, limestone somewhat more than that, and sandstone about twice as much. Taking the expansion of the granite as the basis of calculation, and supposing the crust for a hundred miles in thickness to be undergoing change of temperature, there would be a resulting difference of level

exceeding two and a half feet for each degree of change in temperature, or more than two thousand five hundred feet for a change of one thousand degrees.

This calculation is made upon the supposition that the law of expansion is the same for all temperatures, and that no new conditions are introduced at high temperatures by the presence of aqueous particles. We know, however, that solids expand more rapidly at high temperatures than at low, and the elasticity of aqueous vapor at high temperatures must increase the rate of expansion of the rock through which it is diffused. Although we are not able to introduce, numerically, the effect of these two circumstances, yet it is obvious that they must be considerable.

The mean elevation of land above the level of the sea is about nine hundred feet, the mountain masses above that level not being included; and the estimated mean depth of the ocean, not including its chasms, does not exceed two thousand six hundred feet. The *total elevation of the continental masses*, for which it is necessary to account, does not therefore exceed three thousand five hundred feet. This amount of vertical movement may evidently be produced by the expansion and contraction resulting from changes of temperature.

These changes of level must, however, be very gradual. Any diminution of temperature must result from the transfer of heat to the surface; and the conducting power of rocks is very imperfect. The lava in a crater is often so cooled on the surface that it can be walked on, while but a few feet below it is still liquid. Lava currents continue in gradual motion long after the surface is nearly cold. This was the case with one of the currents from Ætna for more than nine months after its eruption, and with another for ten years. Humboldt visited Jorullo forty years after it was thrown up, when the lava around the mountain was still in a heated state, the temperature in the fissures being on the decrease from year to year; but twenty years after its ejection the heat was still sufficient to light a cigar at the depth of a few inches. If so long a period is insufficient to solidify a comparatively small

quantity of melted rock when the circumstances for cooling are most favorable, we may well suppose that centuries would be required to abstract sufficient heat from the earth's crust to produce any material change in the areas of continents.

If this account of the elevation and subsidence of continents is correct, it would seem that they ought to be constantly undergoing change of level. And their *apparent stability* may be regarded as an objection to it. If in any place there is absolutely no vertical movement, then those conditions must exist in which, for the time being, there is no change of temperature.

But it is doubtful whether there ever is absolute stability of any portion of the surface for long periods of time. Of the minor vertical movements of the interior of continents, there can, from the nature of the case, be no evidence whatever. Changes of level, where they are known to be taking place, are so slow, that they are hardly perceptible in the period of a human life. Such changes had been going on for centuries in Sweden before they were suspected. As accurate observations have increased in number, and historical records become available, it is becoming known that a very large amount of the seaboard is undergoing change of level. It becomes probable, then, that these extremely slow changes of level are constantly and everywhere taking place.

That portion of the crust of the earth constituting the present continents, being further removed from the centre, would part with its heat more rapidly, and receive heat from the central mass more slowly, than that portion which at present constitutes the bed of the sea. The continents are therefore in a situation to undergo contraction and depression, and the bed of the sea is most favorably situated for rising. If the distribution of water through the mass has any influence in promoting its expansion, then the bed of the sea would receive this supply most abundantly, and the continents the least so. We see, then, in nature, those provisions for an alteration of level, which, from the character of the several rock formations, we know to have taken place. When any portion of the earth's surface is covered with the sea, the conditions exist

which will at length elevate it. When it becomes dry land, the conditions exist which will in time depress it below the level of the ocean. Hence, those impressions in regard to the land, as stable beyond the possibility of change, we ought to abandon; and those vertical movements, which, when proved, we are accustomed to regard as extraordinary, we shall, at length, consider as only particular instances of one of the most general laws of nature.

7. *Variations of Climate.* — The only sources of heat by which climate can be affected are the sun and the heated interior of the earth.

If the former melted condition of the entire mass of the earth be assumed, the temperature of the surface must have been increased, by conduction of heat from within, for long periods after the superficial stratum had become solid. It is, however, susceptible of proof, that the present climates are not sensibly affected by interior heat, though at a little more than a mile below the surface the temperature is equal to that of boiling water. At any time, therefore, after the waters had become condensed, collected into oceans, and become sufficiently cool to support the animal life of which the remains are now found, it is not probable that the climate was, to any considerable extent, influenced by the heat conducted from the interior.

Still, there have been great changes of climate since those early organic forms existed; and, since we have no ground for supposing that the temperature of the sun's rays has suffered any reduction, we have to inquire whether the means of retaining the heat from the sun could at any time have been different. *The relative position of land and water* depends, as we have seen, upon igneous causes, and has been very different at different times. We shall find that climate must have been greatly modified by these changes; for the land radiates and absorbs heat freely, and water possesses this power in a very low degree.

Let us suppose the zone comprised between the tropics to be occupied by land, and the portions without these limits to be covered with water. Under these conditions, the land, having a

nearly vertical sun the whole time, would accumulate heat to a degree scarcely compatible with the existence of animal life. This is sufficiently proved by the oppressive tropical climates of the present time, influenced as they are by polar lands and contiguous seas.

Under the same conditions, the sea would be heated by contact with the land, and the heat would be distributed by marine currents to the polar regions. But the water thus distributed would not part with its heat, because it has but little radiating power, and nowhere comes in contact with polar land. It follows, then, that both land and water would be subjected to a very high temperature.

But, if we suppose the land confined to the polar regions, and the sea to the equatorial, the opposite results would follow. The equatorial sea would absorb but a small proportion of the solar heat which would be thrown upon it. The land would receive the sun's rays too obliquely to receive much elevation of temperature, as the present polar climates show. Hence, the temperature of the earth would differ but little from that of the planetary spaces, which is fifty-eight degrees below zero, a temperature too low to allow of any considerable development of organic life.

These are the conclusions to which we are led by considering the different powers of land and water to absorb and radiate heat, and we shall find that the existing climates are in accordance with these conclusions. America has a lower temperature than Europe in the same latitudes. It has also a smaller proportion of land in the equatorial regions, and a greater proportion in the north polar regions. The eastern continent is colder in Asia than in Europe in the same latitudes. It has also less equatorial and more polar land. The southern is colder than the northern hemisphere at equal distances from the equator. There is also less land near the equator on the south side, and probably as much land around the south as the north pole.

Hence, we see that there may have been such a relation of land and water as to account for all the variations of temperature which

are known to have existed. We cannot say that such actually has been the case. We can tell, with some degree of accuracy, what portions of the present continents were land at the several geological periods; but three-fourths of the surface of the earth is covered with water, and of the condition of this portion during those periods we have no means even of conjecturing. We can only say, that, by the operation of known causes, the relative position of land and water may have been such as to produce the climates known to have existed at former periods of the history of the earth.

# INDEX.



13*

## J.



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## S.

# QUESTIONS

TO

# ELEMENTS OF GEOLOGY.

14

# QUESTIONS.

## CHAPTER I.

### SECTION I.

How many elementary substances are known?

In what combinations is oxygen found? What proportion of the earth's crust consists of it?

In what combinations does hydrogen occur? Nitrogen? Carbon? Sulphur? Chlorine? Fluorine? Iron? Manganese?

How does silicium occur? Aluminium? Potassium? Sodium? Calcium? Magnesium?

How are these elementary substances classified? (Silicium, or silicon, has but a doubtful claim to be regarded as metallic.)

### SECTION II.

What is a simple mineral? How many are known?

What are the physical properties of quartz? How are the several varieties distinguished?

What are the physical properties of felspar? Mica? Hornblende? How are its varieties distinguished? Augite? Hypersthene? Talc? How are its varieties distinguished? Serpentine? Carbonate of lime? Gypsum? Its varieties?

What other minerals are mentioned?

### SECTION III.

Define the crust of the earth. Rocks.

What are the unstratified rocks?

What is the structure of granite?

How are the varieties distinguished?

What is the porphyritic structure?

Describe hypersthene rock.

What are volcanic rocks? Lava? Scoriæ? Pumice-stone?

How is the vesicular structure produced?

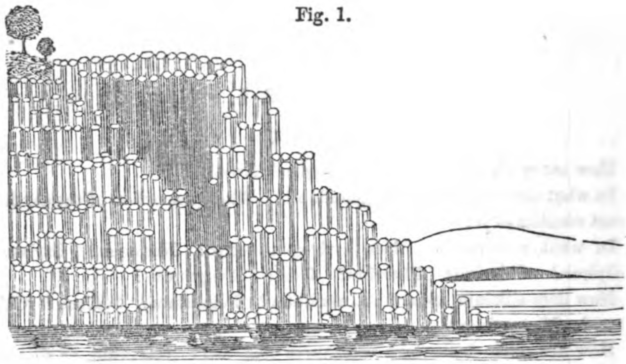
What are volcanic breccias? Volcanic grits?

What is the composition of the trappean rocks?

What is the amygdaloidal structure?

What are the three varieties of trappean rocks, and how are they distinguished?

Fig. 1.



Name the stratified rocks. Describe gneiss. Mica slate. Sandstone. Conglomerate. Greensand. Describe the varieties of limestone.

What is dolomite? Of what does clay consist? Clay slate? What modifications does clay slate present? What is diluvium?

## CHAPTER II.

### SECTION I.

What is the primary division of rocks?

Upon what principle are the unstratified rocks divided?

Upon what principle are the stratified rocks divided?

Why are the non-fossiliferous called metamorphic rocks?

Name the four classes of rocks.

### SECTION II.

What is the most abundant plutonic rock?

How is its thickness ascertained?

What is its amount?

Where is it found?

What is its ordinary structure?

What peculiarity of structure facilitates the cleavage of granite?

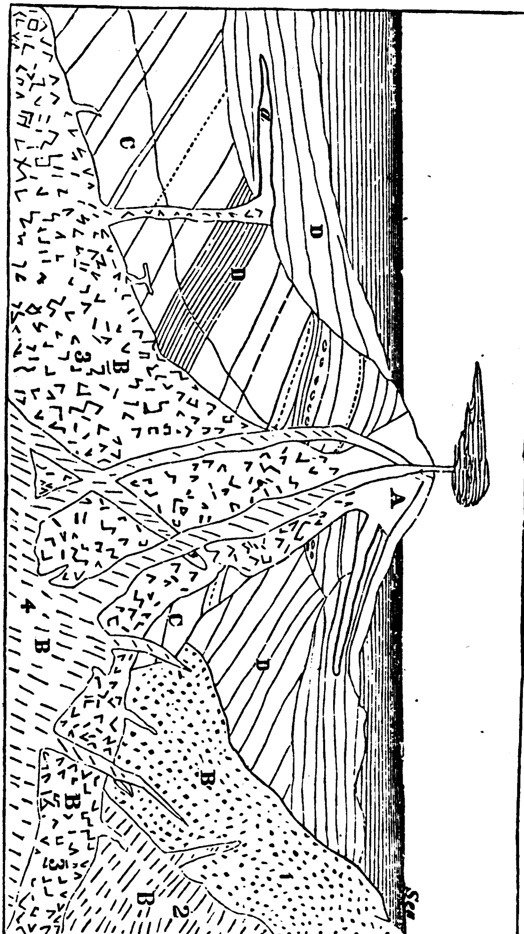



Fig. 2.

The granitic masses are generally deep below the surface; in what other position does granite appear?

Fig. 3.

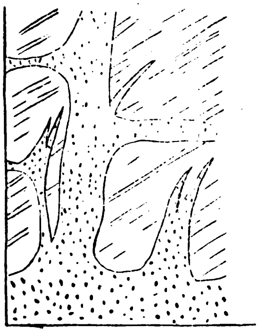
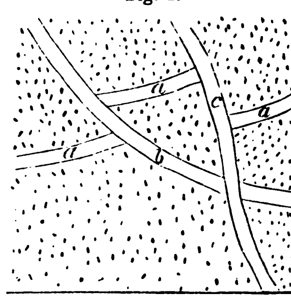


Fig. 4.




In what classes of rocks are granite veins found?

Were they all produced at the same time?

How is this demonstrated?

What is the relative position of the older and newer granites?

What other plutonic rocks occur in considerable quantities?

SECTION III.

Of what do volcanic rocks consist?

In what states are they ejected?

What are the principal varieties of lava, and how are they distinguished?

Why is the basaltic lava the last to be ejected?

How is the age of the volcanic rocks determined?

What are the three divisions of the volcanic rocks, as dependent upon age?

What is the proportion of the volcanic to other rocks?

How many active volcanoes exist?

Describe the eruptions of Kilauea.

Describe the eruption in Iceland in 1783.

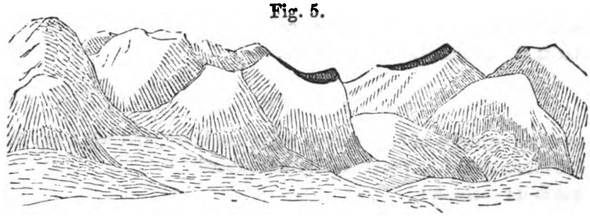
What are the dimensions of Mount Ætna, and how has it been produced?

How are the tertiary lavas known to be such?

Where have they been most studied?

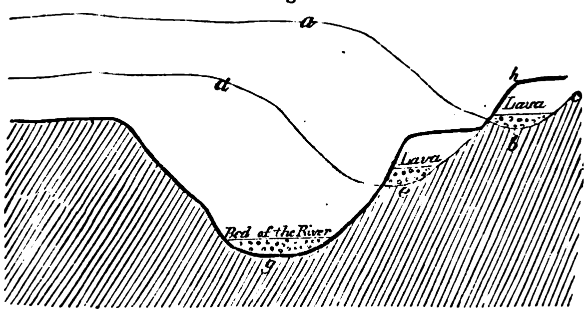
**What is the evidence that these rocks in France are volcanic?**
**Have these lavas been produced within the historic period?**

Fig. 5.



**Were they produced at an early period in the earth's history?**
**Give the evidence that their activity was long-continued.**

Fig. 6.




**What is the form of the earlier volcanic rocks?**
**What circumstances distinguish the trappean from other volcanic rocks?**
**What are some of the prominent localities of the trappean rocks?**
**How do they occur in the islands west of Scotland?**
**How in the valley of the Connecticut river?**

SECTION IV.

**What is the lowest metamorphic rock?**
**Describe it.**
**How does mica slate differ from gneiss?**
**Is it well distinguished from argillaceous slate?**
**What is the third rock in the metamorphic series?**
**Why is it difficult to determine the upper limit of this series?**

Why do the principal rocks of this series occur in the order here given?

What other rocks may take the place of these principal rocks?

Where do the metamorphic rocks occur?

What is their thickness and amount?

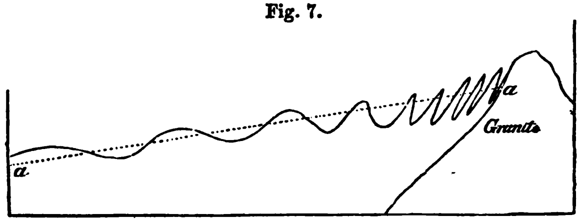
SECTION V.

How many systems of fossiliferous rocks are there, and what are they?

What other system is provisionally introduced?

What is its position?

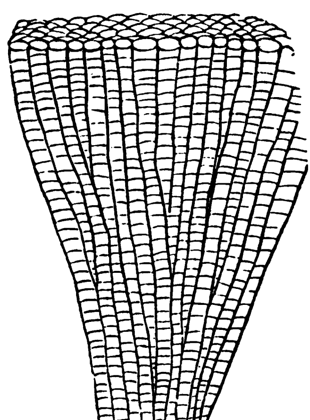
Fig. 7.




Describe it.

What materials of value are obtained from this system?

Fig. 8.



What fossils does it contain?

In what localities is it found?

What explanation, in reference to these rocks, is given by those who deny that they constitute a distinct system?

Fig. 9.

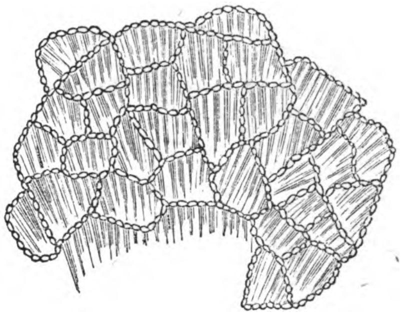
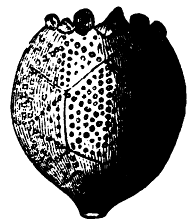


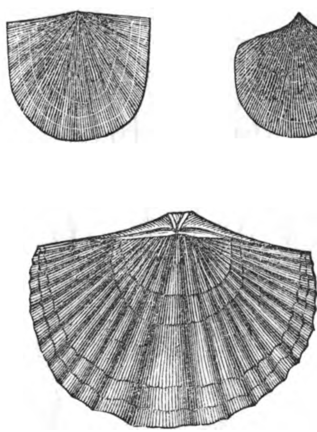
Fig. 10.



In what respects does the State of New York present the best facilities for studying the silurian system?

Describe the Champlain division.

Fig. 11.



The Ontario division.

The Helderberg division.

Fig. 12.

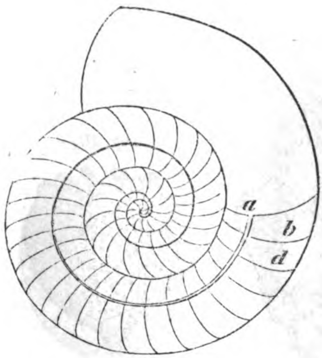



Fig. 15.

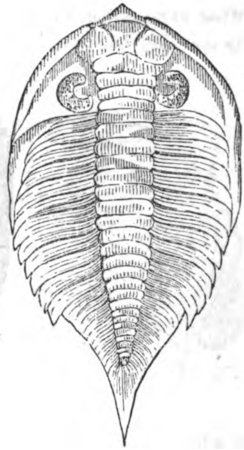


Fig. 13.

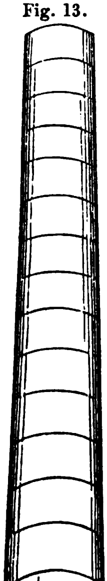


Fig. 14.

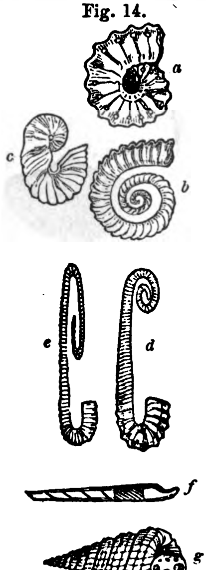
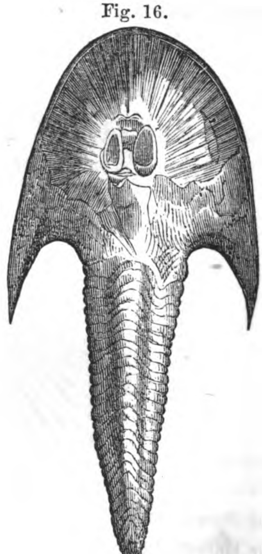
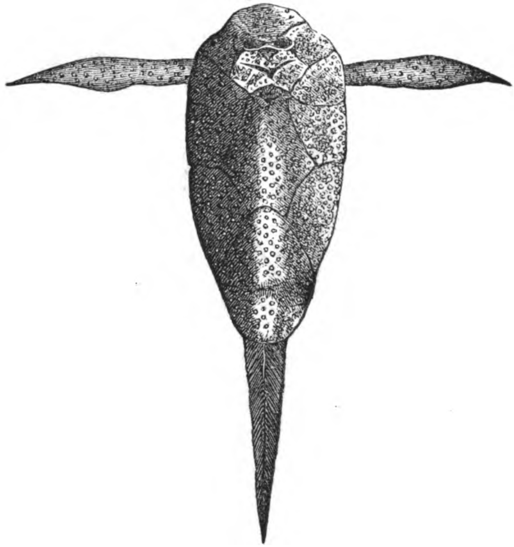



Fig. 16.



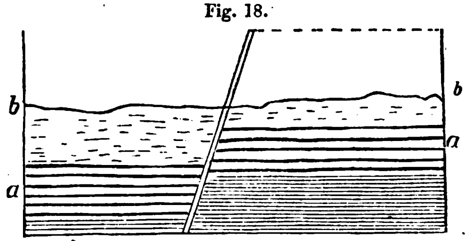
Describe the Erie division.
What are the fossils of this system?

Fig. 17.



Describe the Crinoidea.
The Cephalopoda, and the two forms.

Fig. 18.

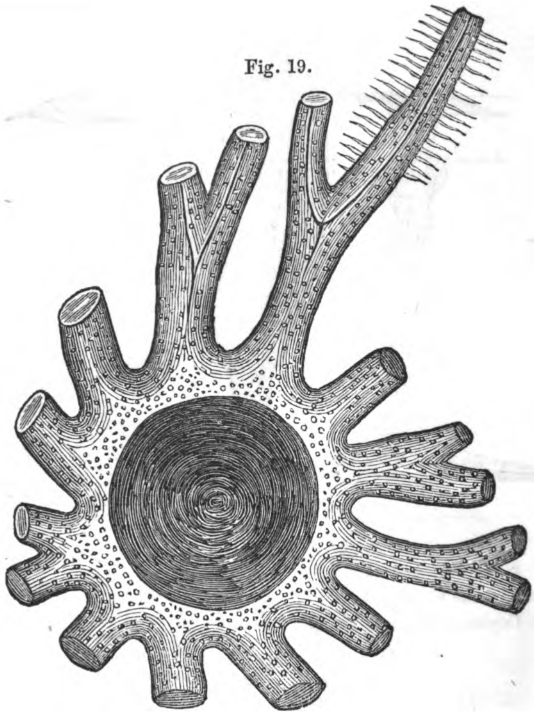



The Trilobite.
What higher forms of animal life existed during the silurian period?
The geographical range of the system?
Of what does the Old Red Sandstone consist?

Describe its three divisions.

What are its fossils?

Fig. 19.



Describe the fishes of that period.

What was the peculiarity of the Pterichthys?

Of the Cephalaspis?

Where are the rocks of this system found?

How is the carboniferous system divided?

Describe the carboniferous limestone.

What ores are found in it?

Describe its fossils.

Describe the millstone grit.

Of what do the coal measures consist?

How does the ironstone occur?

Describe the coal beds.

How is the continuity of the strata interrupted?

What variations from this general type occur in the formation?

Fig. 20.

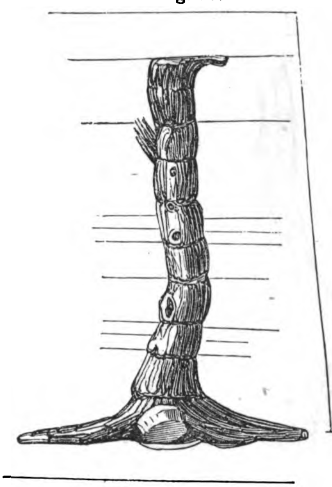
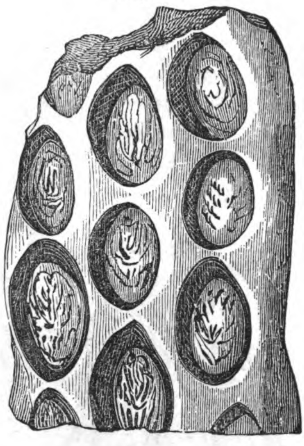


Fig. 21.



Describe the several varieties of coal.

How is the coal quarried?

Fig. 22.


What mineral springs occur in this formation?

To what uses is coal applied?

(The coal was deposited thousands of years ago, and has served no useful purpose, that we know of, till very recently. Its formation was planned and completed to meet a want which was not to be felt till the lapse of many ages. It is a notable instance of the wisdom and fore-

thought, as well as of the benevolence, of God.) In what does this

Fig. 23.

Fig. 24.

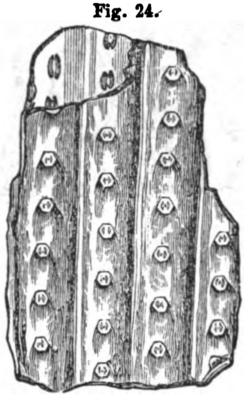
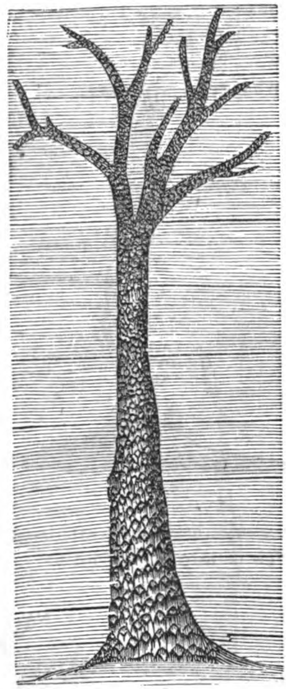
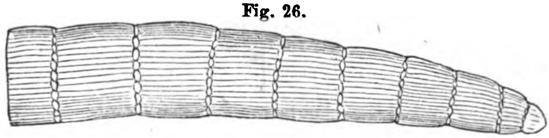


Fig. 25.



prospective arrangement consist? What are the character and position of the fossils of the coal measures?

Fig. 26.



What are the four most abundant forms?

Describe the Stigmaria. The Sigillaria. The Lepidodendron. The Calamite.

Where are the beds of coal found?

What is the fourth formation of rocks?
Into what two portions is it divided?
Of what does the Permian portion consist?
The Trias?
What minerals are found in this formation?
What springs?

Fig. 27.

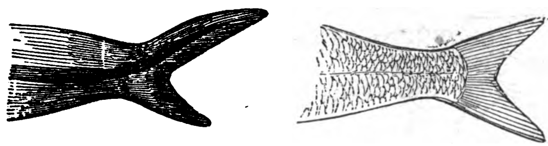


Fig. 28.

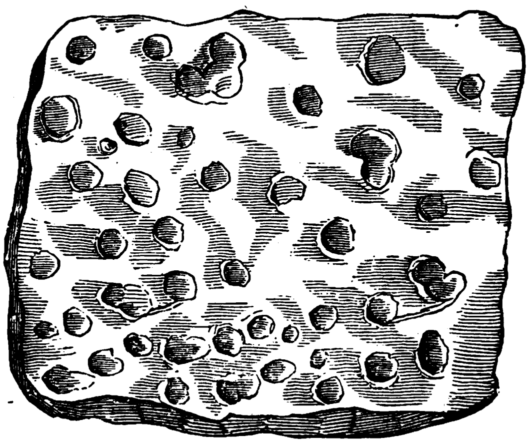
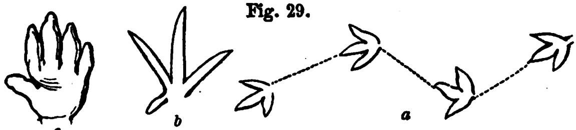


Fig. 29.




What fossils?
How are the fishes of the earlier and later portions distinguished?
What peculiarity of the red sandstones is mentioned?
By what kinds of animals were the tracks, which they contain, made?

Give localities of the new red sandstone.

What are the three divisions of the Oölitic system?

Fig. 31.

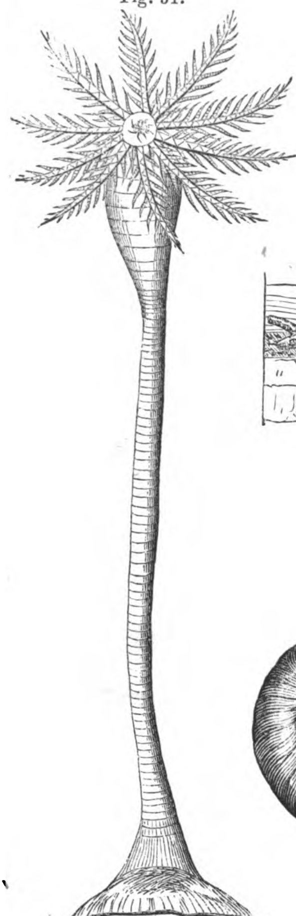


Fig. 30.

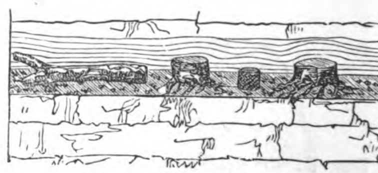


Fig. 32.

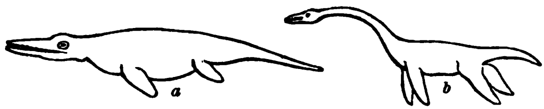
Describe the Lias.

The Oölite.

The Wealden.

What are the general peculiarities of the system?

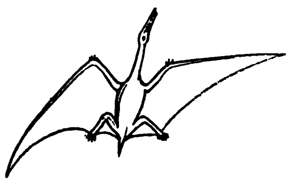
Fig. 33.



What are the fossil animals of the system?

By which class of fossil animals is the system characterized?

Fig. 34.



Describe the Ichthyosaurus. The Plesiosaurus. Pterodactyle. The Iguanodon.

Where is the system developed?

What are the divisions of the Cretaceous system?

How are the layers of chalk separated?

What is the geological position of the Neocomian system, and the greensand of this country?

What are the fossils of this system?

Fig. 35.

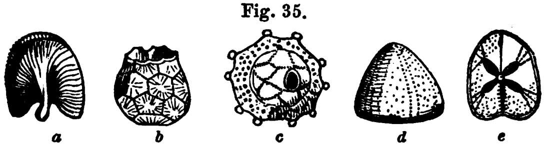
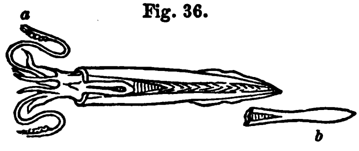


Fig. 36.



What the geographical range?

How are the tertiary deposits distinguished from the older formations?

Upon what principle is the tertiary system divided?
What are these divisions called, and what does each name signify?

Fig. 37.

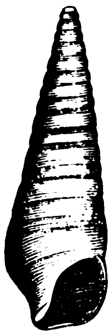


Fig. 38.

Fig. 39.

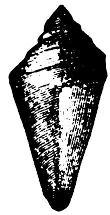


Fig. 40.

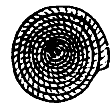


Fig. 41.

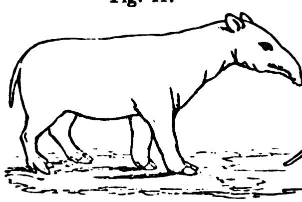


Fig. 42.

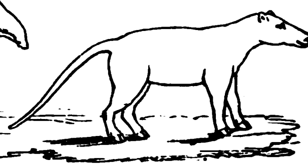
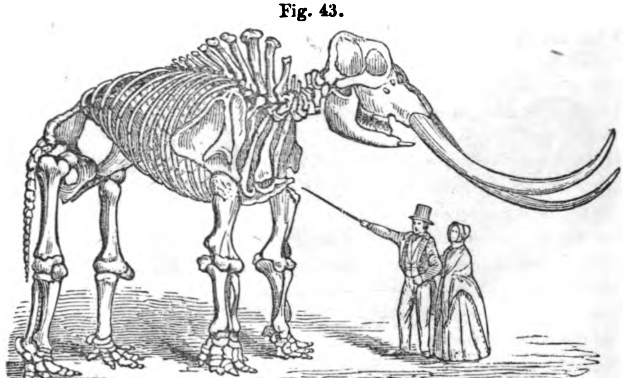


Fig. 43.



In what portion of the tertiary period was the *drift* deposited?

What is the geographical range of the drift?

Of what does it consist?

What is the latest tertiary deposit?

What are the fossils of the tertiary system?

Describe the Paleotherium. The Anoplotherium. The Megatherium. The Mastodon. The Mammoth.

What other animals belonged to this period?

Where are the tertiary deposits found?

What formations are regarded as recent?

What formations of this class are accessible?

What others are in progress?

What are the fossils of this formation?

SECTION VI.

What is a fossil?

In what ways are they preserved?

When is a fossil said to be mineralized?

Describe the process of mineralization.

How is it proved that the removal of the organic matter and substitution of mineral particles are simultaneous?

Were animals created before vegetables?

How is this shown?

At what period was the vegetable growth the greatest?

What forms of animal life were most abundant during the earlier periods?

What vertebrated animals belonged to these periods?

What advance is made in the new red sandstone period?

During what period do the mammalia first appear in abundance?

During what geological period was man created?

How are the footprints and skeletons of human beings in solid rocks accounted for?

Why are not fossils distributed uniformly through all the formations, and through all the parts of each formation?

In what does the importance of fossils consist?

How are the fresh-water and marine formations distinguished?

What circumstances render it difficult to identify rocks of the same age in different localities?

How are formations identified?

Was the work of creation one of short duration?

What was the last work of creation of which we have any geological evidence?

Why may we presume that no more species will be created?

Do all the animal and vegetable species which have been created still exist?

Fig. 44.

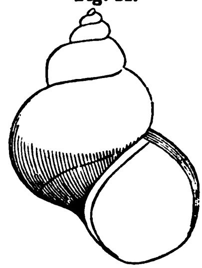
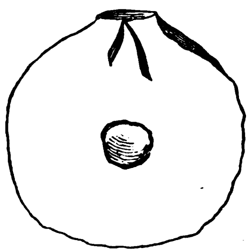


Fig. 45.

Fig. 46.



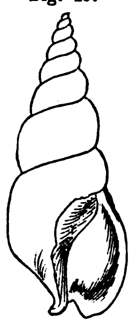
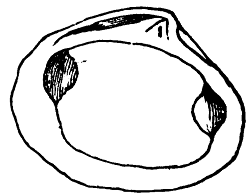


Fig. 47.



What causes are operating to destroy species?

SECTION VII.

How long has it been since the creation of the earth?

How does the amount of stratified rock indicate the great antiquity of the earth?

How does the stratification show the same thing?

What is the proof that the principal strata were deposited before the creation of man, and how does this fact bear upon the question of the antiquity of the earth?

Give the argument drawn from the successive creations and disappearance of animal and vegetable species.

The argument drawn from the amount of organic matter in the stratified rocks.

The argument from slow accumulation.

What is the general conclusion from these facts?

Why is this conclusion an important one?

What objection to it has been raised?

How is this objection answered?

What additional explanation is given?

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## CHAPTER III.

### SECTION I.

What is the deepest geological change of which we have any knowledge?

What are the reasons for supposing that the lowest stratified rocks are undergoing fusion?

Why are the lowest stratified rocks regarded as of mechanical origin?

What changes have they undergone?

### SECTION II.

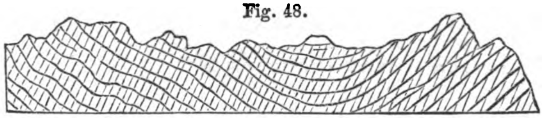
In what state were the stratified rocks deposited?

What change have they undergone in this respect?

How is the fissile structure produced?

How is the cleavage structure produced?

Fig. 48.



What is the third class of changes?

What do fractures at the surface become by the erosion of water?

How are caverns formed?

Describe a vein of segregation. A dike. A mineral vein.

What is a fault?

Were the inclined strata thus deposited?

How is it proved that they have taken the inclined position since they were deposited?

What is the direction of the dip?

What lines form the angle of inclination?

What is the outcrop of inclined strata? The strike?

Fig. 49.

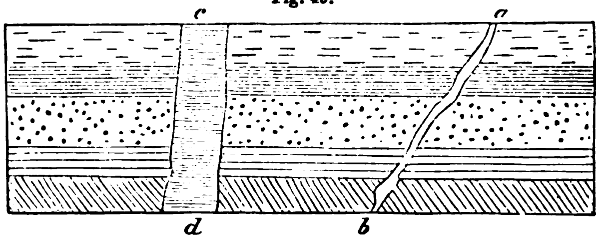



Fig. 50.

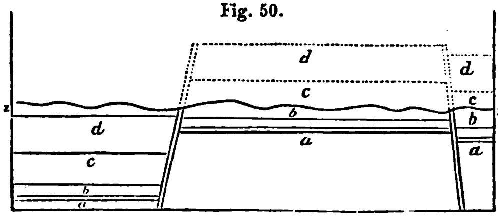



Fig. 51.

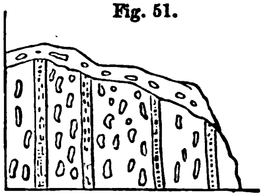


Fig. 52.

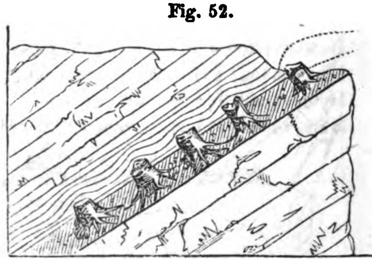
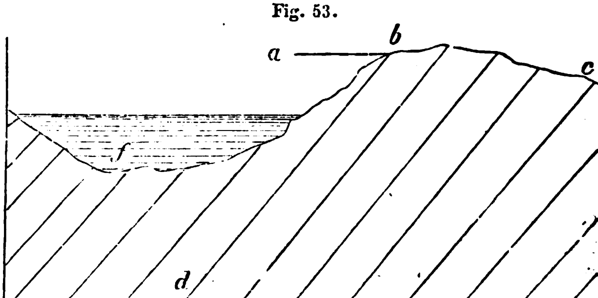
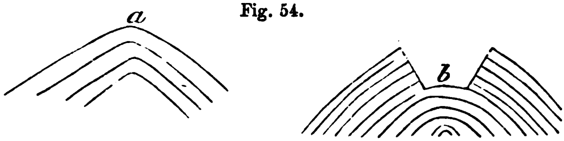


Fig. 53.



Describe an anticlinal axis. A synclinal axis.
A valley of elevation. A valley of subsidence.

Fig. 54.



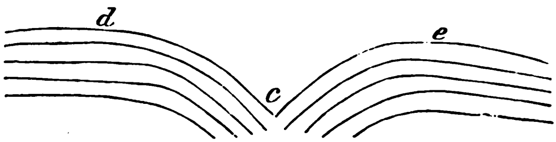




Fig. 55.

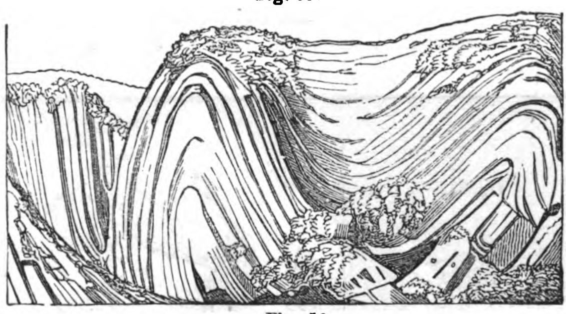
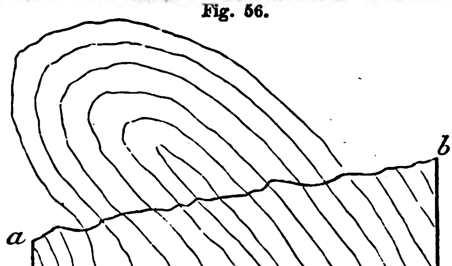


Fig. 56.




When are strata unconformable ?
What other disturbances have taken place in the strata ?
When did these various disturbances take place ?
How is it known that there has been no period of universal disturbance ?

SECTION III.

**How is it known that the mountains have been covered by the ocean?**

Fig. 57.

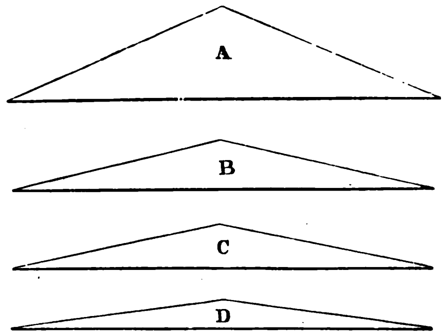
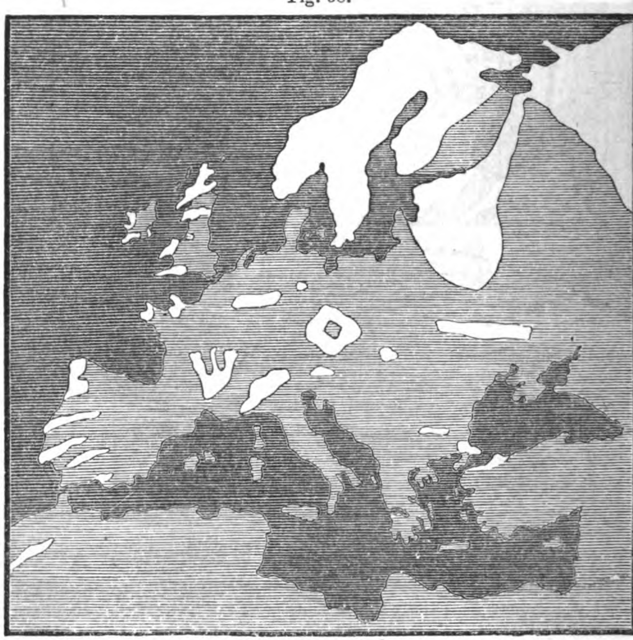



Fig. 58.



Were the granitic ridges thus covered?

Has the level of the sea been, to any considerable extent, fluctuating?

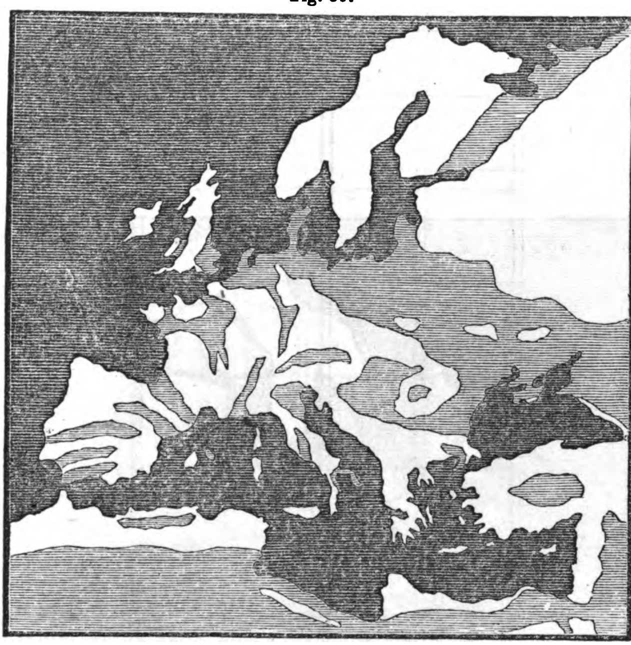
How, then, have the rocks, of which the mountain masses consist, been covered by sea?

Give the evidence that different mountains were elevated at different times.

Has the process of upheaval been sudden or gradual?

How are the mountain valleys, which have the direction of the mountain ranges, been produced?

Fig. 59.



How is the existence of submarine mountains shown?

What is the movement by which continents are elevated?

State the evidence of the elevation of continents from the existence of elevated sea-beaches.

The evidence of the elevation of the coast of Maine.

The evidence of elevation from the existence of lakes.

From the geographical range of the older strata.

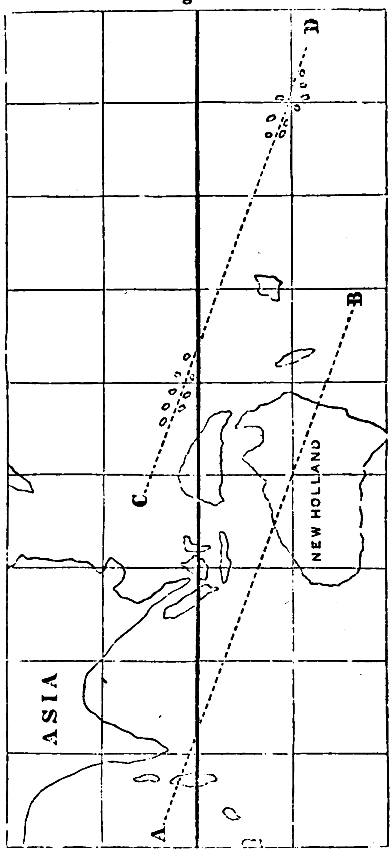
The evidence of the recent elevation of South America.

Of the rising of the north of Europe.

State the proof of subsidence from the occurrence of submerged forests.

Why are these changes but little observed?

Fig. 60.




What are the grounds for asserting that a change of level is taking place over a large area in the Pacific and Indian Oceans?

Fig. 61.

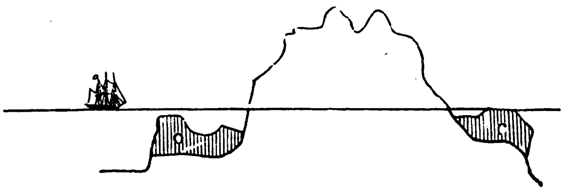



Fig. 62.

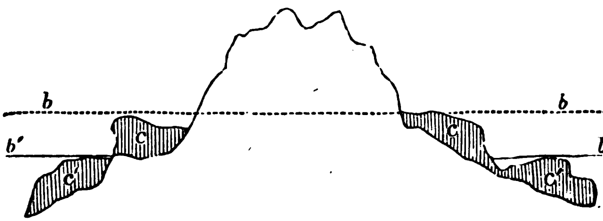



Fig. 63.

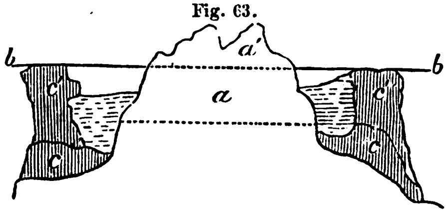
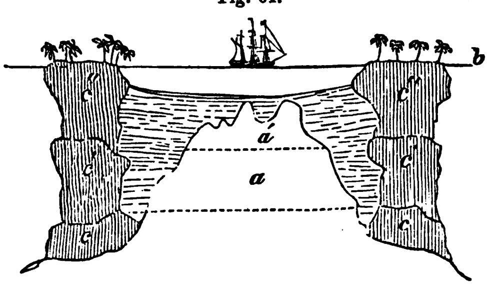



Fig. 64.



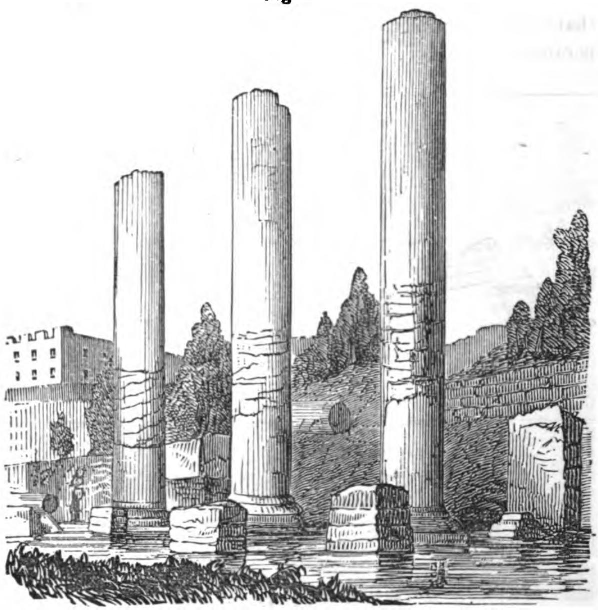
What is the present state of the coast of Greenland in this respect?

Have the changes of level of the same place always been in the same direction?

Give the evidence of elevation and depression in South America.

In Italy.

Fig. 65.



What general conclusion may we draw in respect to the stability of the earth's surface?

To what extent can we ascertain the geography of past epochs?

What former relations of land and water are suggested as not improbable?

SECTION IV.

How can we estimate the denudation which the igneous rocks have suffered?

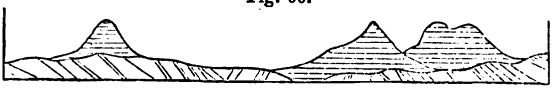
How do faults indicate the denudation of the stratified rocks?

How do valleys indicate denudations?

Describe the instance in Scotland.

What is the evidence of denudation in the Connecticut valley?
How are valleys produced?

Fig. 66.



What is the condition of the surface rock in the colder portions of the temperate zones?

Fig. 67.

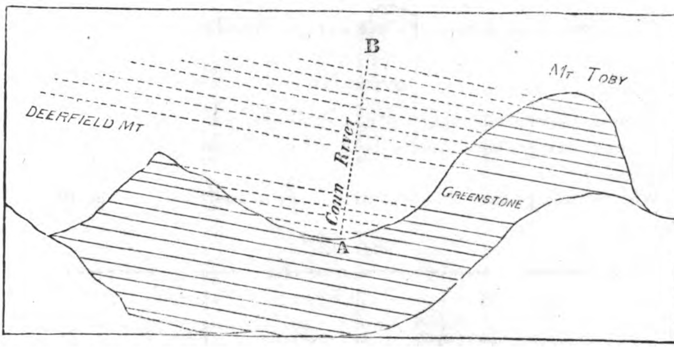
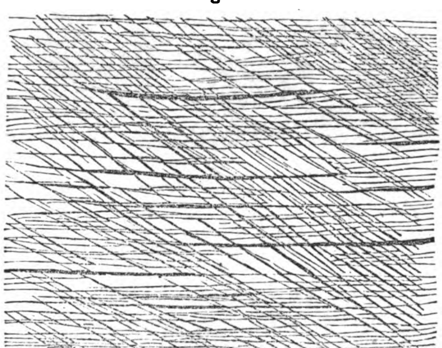



Fig. 68.



With what is the surface rock generally covered?
How are soils formed?
How may soils be improved?
What is necessary to render soils fertile?

SECTION V.

What means have we of judging of the climate of former periods?
What was the climate of the coal period?
What animal fossils indicate a former warm climate?
What evidence that Siberia once enjoyed a milder climate?
Do similar indications appear in the southern hemisphere?
When has the climate of the earth been most uniform?
Has the climate been growing gradually colder to the present time?
What is the evidence of a somewhat recent period of intense cold?
What recent local changes of climate are mentioned as having occurred?

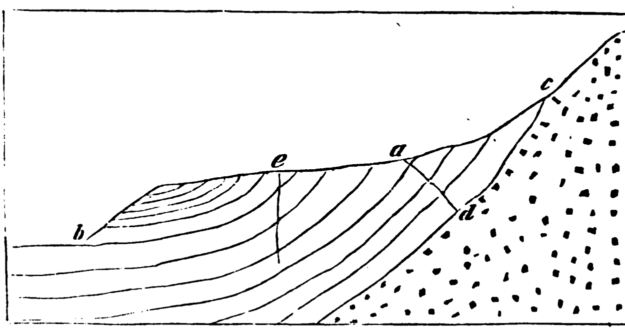
SECTION VI.

State the general advantages of geological changes.

By what changes have the coal-beds and other stratified rocks become accessible?

What advantage from these elevating forces in reference to the granitic rocks?

Fig. 69.




How do these changes affect our means of knowing the structure of the earth?

Explain the origin of springs, wells, and artesian wells?

By what changes have the metallic ores become accessible?

In what light, then, are we to regard disturbances of geological structure?

# CHAPTER IV.

What is the object of the preceding chapters?

How can we arrive at a knowledge of the causes which have produced geological phenomena?

Have geological causes always operated with the same intensity?

How are the means of forming correct geological theories increasing?

## SECTION I.

How does oxygen become an agent in the disintegration of rocks?

How does carbonic acid operate in the disintegration of rocks?

What is the effect of moisture and rain?

What is the effect of variations of temperature?

What other atmospheric causes are mentioned?

How do these causes become important?

What are some of their effects?

## SECTION II.

What are the changes which are to be referred to chemical agency?

Mention some of the disturbances which give rise to chemical changes.

What are the principal effects of chemical action?

How is the cleavage structure accounted for?

Fig. 70.

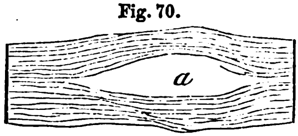
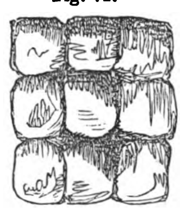



Fig. 71.



Mention instances which show that a cleavage may be established in a body in a solid state.

In it a crystalline arrangement of the particles of the mass?

What other divisional planes exist in rocks?

Mention instances of concretionary formations.

Why may not these concretions have been deposited as nodules?

How have these concretions been formed?

Mention instances of segregation without the concretionary structure.

How was the segregation in these instances effected?

How is the columnar structure produced ?
What is the origin of the mineral veins which are first mentioned ?
How is it shown that other veins are not injected ?
How were these veins formed ?
What is the force by which these molecular changes have been effected ?

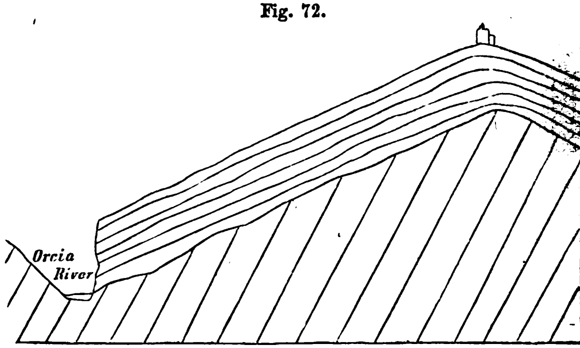
SECTION III.

In what ways are geological changes produced by human agency ?
Of what are the organic remains, in rocks, the record ?
What rocks contain organic materials in large quantity ?
What is the most abundant organic product ?
Explain the mode of growth of corals.
Give instances of extensive coral reefs.
What is the total amount of surface covered by the coral reefs ?

SECTION IV.

What degree of importance is attached to water as a geological agent ?
What are the sources of the sediment which water deposits ?
Why is not the formation of the sedimentary rocks capable of being observed ?
What is the first mode in which solid matter is taken up by water ?
Why are the waters of the ocean saline ?
What effect has the temperature of water in the solution of silex ?
What effect has an alkaline condition of water ?

Fig. 72.




What rock is soluble in water charged with carbonic acid ?
Give an instance of limestone formation from such solutions.

How do rivers furnish sediment for the stratified rocks ?

What determines the position of rapids in rivers ?

What is the effect of water-falls on the abrading action of rivers ?

What is the peculiarity of rock at Niagara which has prevented the fall from becoming a succession of rapids ?

What other circumstance increases the abrading action of rivers ?

What is the principal source of the sediment which is transported by rivers ?

What is the annual amount of sediment furnished by the Kennebec ? The Merrimac ? The Mississippi ? The Ganges ?

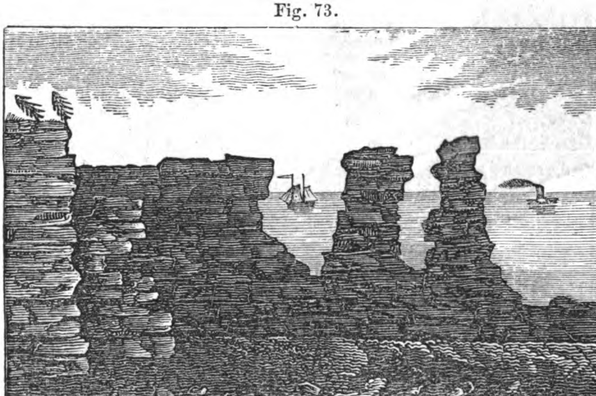
What is the general tendency of these abrading forces ?

What is the effect of waves upon the coast, when it consists of unsolidified materials ?

Describe their effect upon rocky coasts.

How is the encroachment upon such coasts shown ?

Fig. 73.



What is the effect of waves of less power ?

How are marine currents produced ?

How are they increased by the evaporation of the torrid zone ?

What are the most important marine currents ?

Which class of currents have the greater depth ?

Upon what does the power of deep currents depend ?

How would the effect of these currents be increased by earthquakes ?

Where will the effects of these currents be greatest ?

Mention instances of these effects.

Fig. 74.

What must be the effect of such currents as the Gulf-stream and Mozambique channel?

Mention, generally, the effects of these currents.

Why does detrital matter remain suspended in the water of rivers?

How is the coarse and fine sediment separated?

Why do river currents extend some distance into the sea?

What effect does this have in distributing the sediment which the rivers furnish?

Upon what does the transporting power of marine currents depend?

When a river enters a lake, why is its sediment deposited?

Describe the effect.

When is sediment deposited in the beds of rivers?

Describe the effects of this deposition.

Where is most of the sediment deposited?

Give the area of some delta deposits.

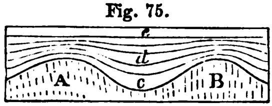
How do the deep-sea deposits now forming compare in extent with the earlier formations?

State the several circumstances by which a succession of deposits would be arranged in strata.

How are those differences produced upon which the separation into independent formations depends?

Why are marine deposits nearly horizontal?

Fig. 75.




How are the irregular stratifications produced?

What peculiarity in the fossils will distinguish the lacustrine and marine deposits?

What peculiarity in reference to fossils will characterize the deep-sea deposits?

How is coal shown to be of vegetable origin?

Why will the drift wood of the sea accumulate in particular localities, and why will it sink?

Why will it become buried beneath earthy matter?

How is it known that wood thus buried will, at length, become lignite?

How is lignite converted into mineral coal?

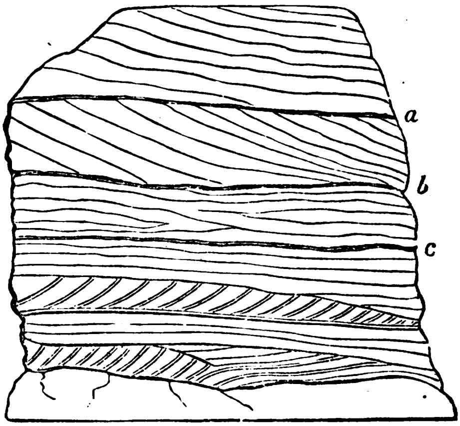
What is the proof of it?

Have beds of coal been formed at other periods, besides the carboniferous?

Is it probable that coal-beds are now forming?

How did the flora of the carboniferous period differ from the existing flora?

Fig. 76.




Are the alternations of the earthy and coal strata satisfactorily explained?

In what portions of the geological series are the deposits of salt found?

Where is saline matter principally stored?

Explain the conjectural formation of salt in the Mediterranean Sea.

What form do rocks take when deposited from a chemical solution?

How is sand or gravel solidified by the infiltration of mineral waters?

What is the effect of drying upon the solidification of rocks?

What is the effect of pressure?

What of heat?

SECTION V.

What is a glacier?

What is the extent of the glaciers of the Alps?

What change does the mass of snow in the higher valleys of the glacier mountains undergo?

What is the source of supply to the glacier?

What is the cause of the motion of the glacier?

What is the usual annual motion?

Why will the glacier melt but little at its under side?

Where will the waste at the surface just equal the addition?

What circumstances vary the position of the terminus of the glacier?

Fig. 77.


What, besides snow and ice, enters into the composition of a glacier? How are these materials supplied?

How is a lateral moraine formed?

What effect has the motion of the glacier on the rocky surface over which it passes?

What is the material by which this effect is produced?

How is the terminal moraine produced?

How may the moraines on the Jura Mountains be explained?

How has it been proposed to explain the striated surfaces of rocks found in the north of Europe and America?

What is the objection to this extension of the glacier theory?

How does the ice accumulate along the coast in high latitudes to form icebergs?

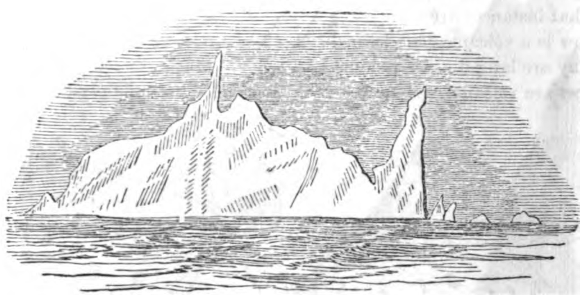
Why does it ultimately separate from the shore?

How does it become freighted with earthy matter?

In what direction do the icebergs float, and why?

What are the dimensions of an iceberg, estimated from the part that is visible?

Fig. 78.



Where does the mass of ice increase, and where diminish?

What will be the effect of its melting?

How is it supposed that icebergs may have striated the rocky surface?

What is probably the condition of the bed of the seas over which icebergs now float?

Has the north of Europe and America been so depressed, during a period comparatively recent, as to admit of this explanation of the drift phenomena?

SECTION VI.

What is the condition of the interior of the earth with respect to heat?

How do the observations made in deep mines and wells prove this?

How far is the temperature influenced from the surface?

What is the general law of increment of temperature?

At what depth would most mineral substances be melted?

How is this conclusion confirmed?

What was probably the original state of the mass of the earth?

What other explanation may be given of this interior heat?

What is the elastic force upon which volcanic phenomena depend?

Upon what does the fluidity of lava depend?

Upon what does its porous structure, when cooled, depend?

Why are volcanoes situated near the sea?

Describe the principal lines of volcanic activity.

What are the forces tending to repress the elasticity of the mass below?

What will be the effect when the elastic is greater than the repressing force?

What produces the phenomena of the earthquake?

What is a volcano?

Why are volcanoes generally arranged a linear direction?

Under what circumstances will a new volcano be formed?

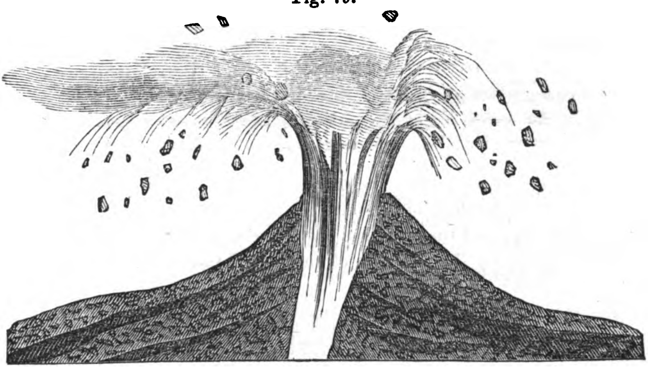
What instances are cited?

How is a volcanic cone formed?

Why are lateral cones produced?

How are volcanic cinders formed? Scoriæ? Volcanic glass?

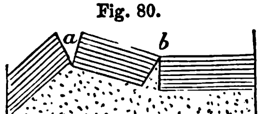
Fig. 79.



Give instances of fractures as results of volcanic action.

How are dikes formed?

Fig. 80.



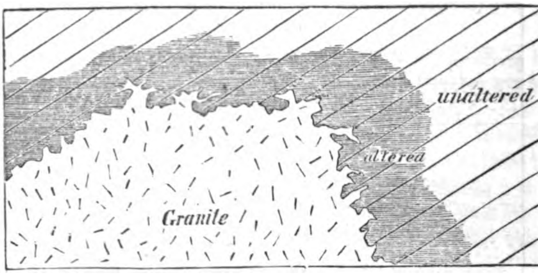

By what agency have the changes in the metamorphic rocks been effected?

Give the instance of metamorphic action from intrusive granite in Norway.

What instance is given as occurring in New Hampshire?

Give the experiment by which it is shown that these changes will result frcm a high temperature.

Fig. 81.




What must be the condition of the lowest stratified rocks in regard to temperature?

Why is not the stratification destroyed?

What changes are produced by this high temperature?

Explain the connection of denudation and earthquake action.

What is the evidence that the surface of the earth is thrown into undulations during earthquakes?

What is the velocity of these undulations?

Give the instance which occurred in Chili.

To what parts of the earth are these undulations limited?

What condition of the surface may be regarded as resulting from this cause?

What is the class of rocks most obviously referable to volcanic agency?

How do the trap rocks differ from ordinary lavas?

Why are they not vesicular?

Why more crystalline?

Why were cones never formed?

What is the proof that the granitic rocks have once been in a melted state?

Why does not the mass of melted rock below the surface retain permanently its liquid form?

Why does it, on cooling, become more crystalline than lava?

State the process by which mountains are formed.

By what law does the elevating force accumulate?

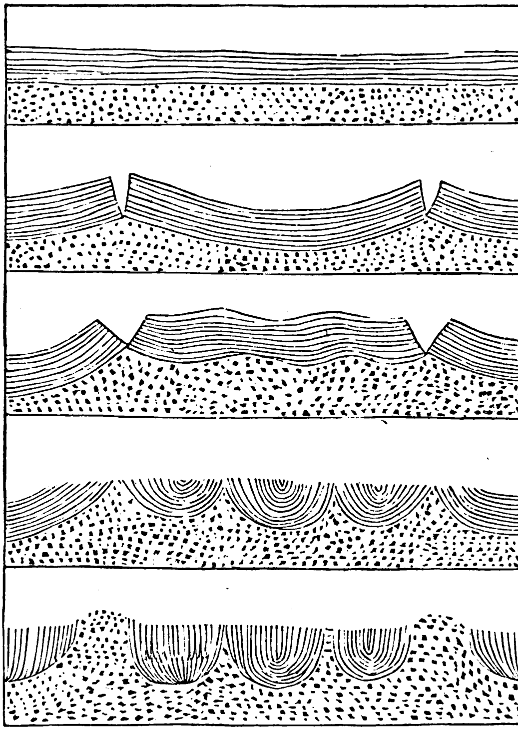
Why, then, is the process of elevation spasmodic, and not constant?

How is the inclined position of strata produced?

How are strata brought into a vertical position over large areas?

Why do subsidences occasionally follow these movements of elevation? Mention instances.

Fig. 82.



What explanation is suggested of deep and extensive chasms?

What conditions must exist together, in the force by which continents are produced?

What cause fulfils these conditions?

What is the proof that the temperature under given localities is variable?

What will be the result of these variations?

What is the law of expansion of rocks, as obtained by experiment?

What amount of change of level may be thus accounted for?

What circumstances would probably increase this amount?

What amount of vertical movement must be accounted for?

Why must these changes of level be very slow?

Under what conditions would there be no change of level?

Is it probable that these conditions exist to any great extent?

Why, then, are not the changes of level observed?

Why is the bed of the sea most likely to experience the change of elevation?

Why are the continents most favorably situated to undergo depression?

What are the sources of heat upon which climate depends?

Does the interior temperature sensibly affect the present climates?

What cause may be assigned for the changes of climate which are known to have taken place?

What are the relations of land by which the highest temperature would be produced?

How would this distribution of land affect the temperature of the waters of the ocean?

What would result if the opposite relations of land and water existed?

What confirmation of these conclusions is drawn from the existing climates of different parts of the earth?

Is there any reason to suppose that the relations of land and water which would have produced a warmer climate in former times did not exist?

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